3. SUMMARY OF WESTERN NORTH PACIFIC AND NORTH INDIAN OCEAN TROPICAL CYCLONES

3.1 WESTERN NORTH PACIFIC OCEAN TROPICAL CYCLONES

The year of 1993 included 21 typhoons (including 3 super typhoons), 9 tropical storms and 8 tropical depressions (Table 3-1). The calendar year total of 38 significant tropical cyclones in the western North Pacific (8 over the average) was the highest since 1967 when there were 41 (Table 3-2). The high number (8) of tropical cyclones reaching only tropical-depression intensity has not been equaled since 1966 which may be due, in part, to a concerted effort to identify significant tropical cyclones early in their life cycle. The year's total of three super typhoons was one short of the 24-year (1970-1993) average for western North Pacific super typhoons (Figure 3-1). The year's total of 30 named tropical cyclones was two above the 34-year average (1960-1993) (Figure 3-2). Thirty-five of the 38 tropical cyclones in the western North Pacific during 1993 originated in

Table 3-1 WESTERN NORTH PACIFIC SIGNIFICANT TROPICAL CYCLONES FOR 1993

TROPICAL CYCLONE		PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	ESTIMATED MAXIMUM SURFACE WINDS KT (M/SEC)	ESTIMATED MSLP (MB)
01W	TD	01 MAR - 02 MAR	5	25 (13)	1002
02W	TS IRMA	10 MAR - 17 MAR	27	55 (28)	984
03W	TD	12 APR - 14 APR	5	25 (13)	1002
04W	TD	20 APR - 27 APR	31	30 (15)	1000
05W	TS JACK	17 MAY - 22 MAY	20	35 (18)	997
06W	STY KORYN	15 JUN - 29 JUN	51	130 (67)	910
07W	TD	17 JUN - 20 JUN	12	30 (15)	1000
08W	TY LEWIS	07 JUL - 12 JUL	23	85 (44)	958
09W	TS MARIAN	13 JUL - 17 JUL	16	45 (23)	991
10W	TY NATHAN	19 JUL - 25 JUL	25	70 (36)	972
11W	TS OFELIA	25 JUL - 25 JUL	12	45 (23)	991
12W	TY PERCY	27 JUL - 30 JUL	12	65 (33)	976
13W	TY ROBYN	01 AUG - 10 AUG	38	120 (62)	922
14W	TY STEVE	06 AUG - 12 AUG	28	65 (33)	976
15W	TD	13 AUG - 14 AUG	6	25 (13)	1002
16W	TY TASHA	15 AUG - 22 AUG	29	80 (41)	963
17W	TY VERNON	21 AUG - 28 AUG	26	80 (41)	963
18W	TS WINONA	22 AUG - 29 AUG	30	45 (23)	991
19W	STY YANCY	29 AUG - 04 SEP	26	130 (67)	910
01C	TY KEONI	20 AUG - 28 AUG	35	100 (51)	944
20W	TS ZOLA	05 SEP - 09 SEP	16	55 (28)	984
21W	TY ABE	09 SEP - 15 SEP	25	110 (57)	933
22W	TY BECKY	14 SEP - 17 SEP	13	65 (33)	976
23W	TY CECIL	22 SEP - 27 SEP	21	100 (51)	944
24W	TY DOT	23 SEP - 27 SEP	18	80 (41)	963
25W	STY ED	30 SEP - 08 OCT	34	140 (72)	898
26W	TY FLO	01 OCT - 08 OCT	30	70 (36)	972
27W	TS GENE	06 OCT - 10 OCT	15	35 (18)	997
28W	TD	07-09 OCT/12-13 OCT	13	25 (13)	1002
29W	TS HATTIE	19 OCT - 25 OCT	23	50 (26)	991
30W	TY IRA	27 OCT - 05 NOV	34	120 (62)	922
31W	TS JEANA	05 NOV - 12 NOV	30	50 (26)	987
32W	TD	18 NOV - 19 NOV	5	25 (13)	1002
33W	TD	18 NOV - 19 NOV	3	25 (13)	1002
34W	TY KYLE	19 NOV - 24 NOV	19	95 (49)	949
35W	TY LOLA	02 DEC - 09 DEC	30	105 (54)	938
36W	TY MANNY	03 DEC - 15 DEC	50	120 (62)	922
37W	TY NELL	23 DEC - 28 DEC	17	70 (36)	972
		TOTAL:	853		

Table 3-2 DISTRIBUTION OF WESTERN NORTH PACIFIC TROPICAL CYCLONES FOR 1959 - 1993

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1959	0	1	1	1	0	1	3	8	9	3	2	2	31
	000	010	010	100	000	001	111	512	423	210	200	200	17 7 7
1960	1	0	1	1	1	3	3	9	5	4	1	1	30
	001	000	001	100	010	210	210	810	041	400	100	100	19 8 3
1961	1	1	1	1	4	6	5	7	6	7	2	1	42
	010	010	100	010	211	114	320	313	510	322	101	100	20 11 11
1962	0	1	0	1	3	0	8	8	7	5	4	2	39
	000	010	000	100	201	000	512	701	313	311	301	020	24 6 9
1963	0	0	1	1	0	4	5	4	4	6	0	3	28
	000	000	001	100	000	310	311	301	220	510	000	210	19 6 3
1964	0	0	0	0	3	2	8	8	8	7	6	2	44
	000	000	000	000	201	200	611	350	521	331	420	101	26 13 5
1965	2	2	1	1	2	4	6	7	9	3	2	1	40
	110	020	010	100	101	310	411	322	531	201	110	010	21 13 6
1966	0	0	0	1	2	1	4	9	10	4	5	2	38
	000	000	000	100	200	100	310	531	532	112	122	101	20 10 8
1967	1	0	2	1	1	1	8	10	8	4	4	1	41
	010	000	110	100	010	100	332	343	530	211	400	010	20 15 6
1968	0	1	0	1	0	4	3	8	4	6	4	0	31
	000	001	000	100	000	202	120	341	400	510	400	000	20 7 4
1969	1	0	1	1	0	0	3	3	6	5	2	1	23
	100	000	010	100	000	000	210	210	204	410	110	010	13 6 4
1970	0	1	0	0	0	2	3	7	4	6	4	0	27
	000	100	000	000	000	110	021	421	220	321	130	000	12 12 3
1971	1	0	1	2	5	2	8	5	7	4	2	0	37
	010	000	010	200	230	200	620	311	511	310	110	000	24 11 2
1972	1	0	1	0	0	4	5	5	6	5	2	3	32
	100	000	001	000	000	220	410	320	411	410	200	210	22 8 2
1973	0	0	0	0	0	0	7	6	3	4	3	0	23
	000	000	000	000	000	000	430	231	201	400	030	000	12 9 2
1974	1	0	1	1	1	4	5	7	5	4	4	2	35
	010	000	010	010	100	121	230	232	320	400	220	020	15 17 3
1975	1	0	0	1	0	0	1	6	5	6	3	2	25
	100	000	000	001	000	000	010	411	410	321	210	002	14 6 5
1976	1	1	0	2	2	2	4	4	5	0	2	2	25
	100	010	000	110	200	200	220	130	410	000	110	020	14 11 0
1977	0	0	1	0	1	1	4	2	5	4	2	1	21
	000	000	010	000	001	010	301	020	230	310	200	100	11 8 2
1978	1	0	0	1	0	3	4	8	4	7	4	0	32
	010	000	000	100	000	030	310	341	310	412	121	000	15 13 4
1979	1	0	1	1	2	0	5	4	6	3	2	3	28
	100	000	100	100	011	000	221	202	330	210	110	111	14 9 5
1980	0	0	1	1	4	1	5	3	7	4	1	1	28
	000	000	001	010	220	010	311	201	511	220	100	010	15 9 4
1981	0	0	1	1	1	2	5	8	4	2	3	2	29
	000	000	100	010	010	200	230	251	400	110	210	200	16 12 1
1982	0	0	3	0	1	3	4	5	6	4	1	1	28
	000	000	210	000	100	120	220	500	321	301	100	100	19 7 2
1983	0	0	0	0	0	1	3	6	3	5	5	2	25
	000	000	000	000	000	010	300	231	111	320	320	020	12 11 2
1984	0	0	0	0	0	2	5	7	4	8	3	1	30
	000	000	000	000	000	020	410	232	130	521	300	100	16 11 3
1985	2	0	0	0	1	3	1	7	5	5	1	2	27
	020	000	000	000	100	201	100	520	320	410	010	110	17 9 1
1986	0	1	0	1	2	2	2	5	2	5	4	3	27
	000	100	000	100	110	110	200	410	200	320	220	210	19 8 0
1987	1	0	0	1	0	2	4	4	7	2	3	1	25
	100	000	000	010	000	110	400	310	511	200	120	100	18 6 1

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YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1988	1	0	0	0	1	3	2	5	8	4	2	1	27
	100	000	000	000	100	111	110	230	260	400	200	010	14 12 1
1989	1	0	0	1	2	2	6	8	4	6	3	2	35
	010	000	000	100	200	110	231	332	220	600	300	101	21 10 4
1990	1	0	0	1	2	4	4	5	5	5	4	1	31
	100	000	000	010	110	211	220	500	410	230	310	100	21 9 1
1991	0	0	2	1	1	1	4	8	6	3	6	0	32
	000	000	110	010	100	100	400	332	420	300	330	000	20 10 2
1992	1	1	0	0	0	3	4	8	5	6	5	0	33
	100	010	000	000	000	210	220	440	410	510	311	000	21 11 1
1993	0	0	2	2	1	2	5	8	5	6	4	3	38
	000	000	011	002	010	101	320	611	410	321	112	300	21 9 8
(1959-1993)													
MEAN	0.6	0.3	0.6	0.8	1.2	2.1	4.5	6.3	5.6	4.6	3.0	1.4	31.1
CASES	20	10	22	27	43	75	156	222	197	162	105	49	1088

The criteria used in Table 3-2 are as follows:

1) If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.

2) If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.

3) If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

TABLE 3-2 LEGEND

Total for the month/year → 38

Typhoons → 21

Tropical Storms → 9

Tropical Depressions → 8

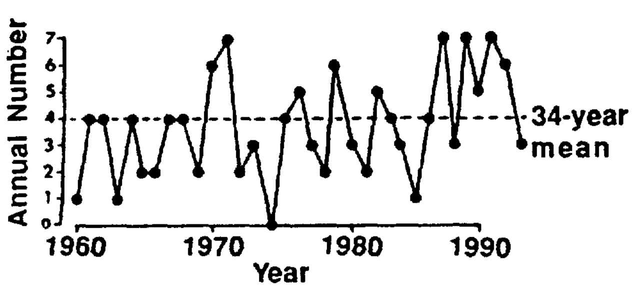


Figure 3-1 Number of western North Pacific super typhoons (1960-1993)

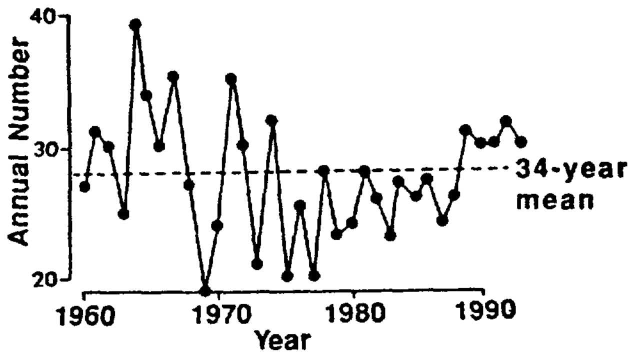


Figure 3-2 Tropical cyclones of tropical storm or greater intensity in the western North Pacific (1960-1993)

the low-level monsoon trough or near-equatorial trough. Two — Ofelia (11W) and Percy (12W) — formed in the peripheral cloud band of a monsoon gyre; and one — Keoni (01C) — formed in the trade-wind trough of the central Pacific. There were no tropical cyclones that formed in subtropical latitudes in direct association with cyclonic cells in the tropical upper-tropospheric trough (TUTT) during this season.

El Niño conditions prevailed in the tropical Pacific during most of 1993: the sea surface temperature (SST) of the eastern equatorial Pacific was consistently warmer than normal, and the Southern Oscillation Index (SOI) (Climate Analysis Center, 1993) remained negative until very late in the year when it returned to near normal (Figure 3-3a). By comparison, the evolution of the SST and SOI in 1993 was somewhat similar to a composite of several past El Niño events (Figure 3-3b) (Rasmusson and

Carpenter, 1982). During January through October of 1993, the low-level wind of the tropical western Pacific featured an eastward displacement — with respect to climatology — of monsoonal westerlies (Figure 3-4). This wind pattern is commonly observed during occurrences of El Niño. In addition to the eastward displacement of monsoonal westerlies in low latitudes, the low-level westerly wind flow associated with the Mei-yu (Chinese for: plum rains) front was more persistent than normal and lasted into August (Figure 3-4). The Mei-yu front is a semi-permanent low-pressure trough of the east Asian subtropics during spring and early summer which extends eastward from near Taiwan into the ocean area southeast of Japan. The lingering Mei-yu front's associated cloud band, and the impact of several typhoons, resulted in a very cool and wet summer for Japan.

With the anomalous eastward push of monsoonal westerlies, many of the year's tropical cyclones formed east of 145°E in the eastern Caroline and Marshall islands (Figure 3-5a), and the mean genesis location of all tropical cyclones during 1993 was south and east of normal (Figure 3-5b) — yet another characteristic of El Niño years. In the 24-year period, 1970-1993, the mean genesis location for 1993 was the southernmost of record (Figure 3-5b). The fact that eight of the year's first nine tropical cyclones formed south of 10°N certainly contributed to pushing the mean genesis location southward, as did the complete lack of genesis of tropical cyclones north of 20°N and east of 160°E, a region more favored for tropical cyclogenesis during non-El Niño years (Lander, 1994). The 1993 Atlantic Hurricane Season also featured this peculiar tendency for storms to form and remain at very low latitudes, impacting Venezuela, Nicaragua and Honduras.

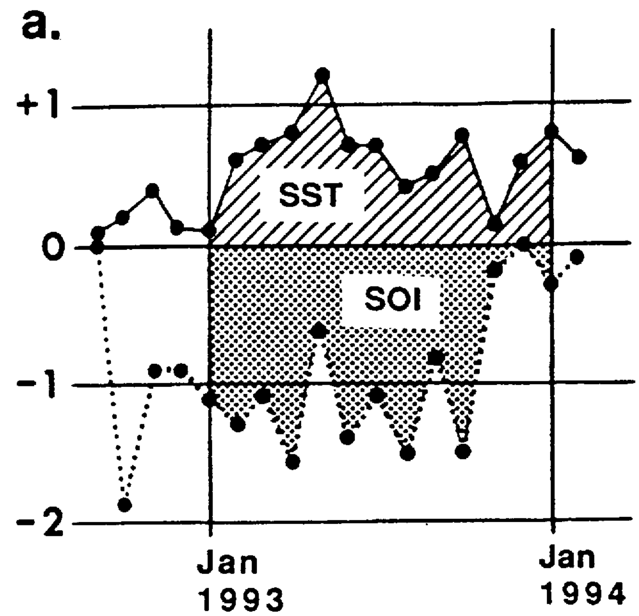


Figure 3-3a Anomalies from the monthly mean for eastern equatorial Pacific Ocean sea surface temperature (SST) (hatched) in degrees Celsius and the Southern Oscillation Index (SOI) (shaded) for 1993. (adapted from Climate Analysis Center, 1993 and Australian Bureau of Meteorology, 1993)

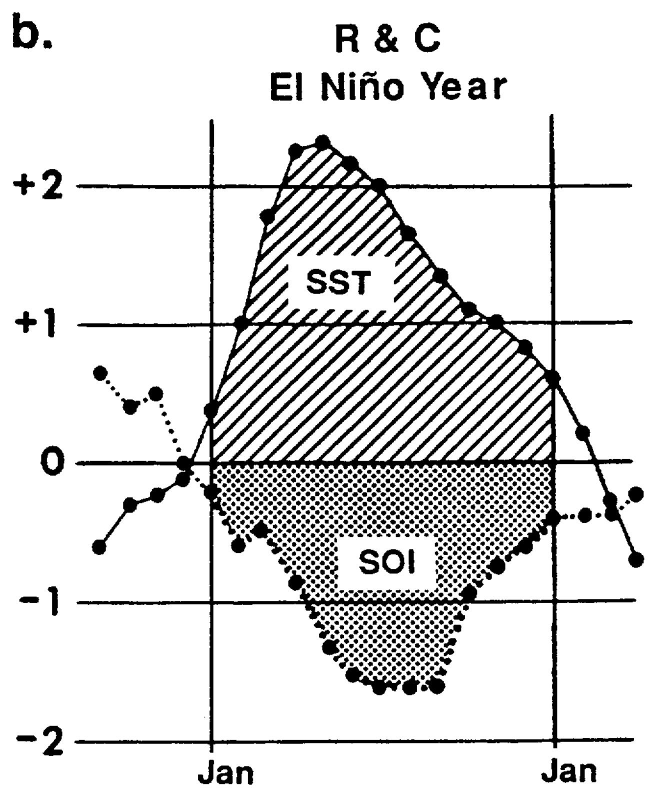


Figure 3-3b Composites of the eastern equatorial Pacific SST anormaly (hatched), and of the SOI (shaded), for six El Nino events (1951, 1953, 1957, 1965, 1969, 1972) [after Rasmusson and Carpenter (R&C), 1982].

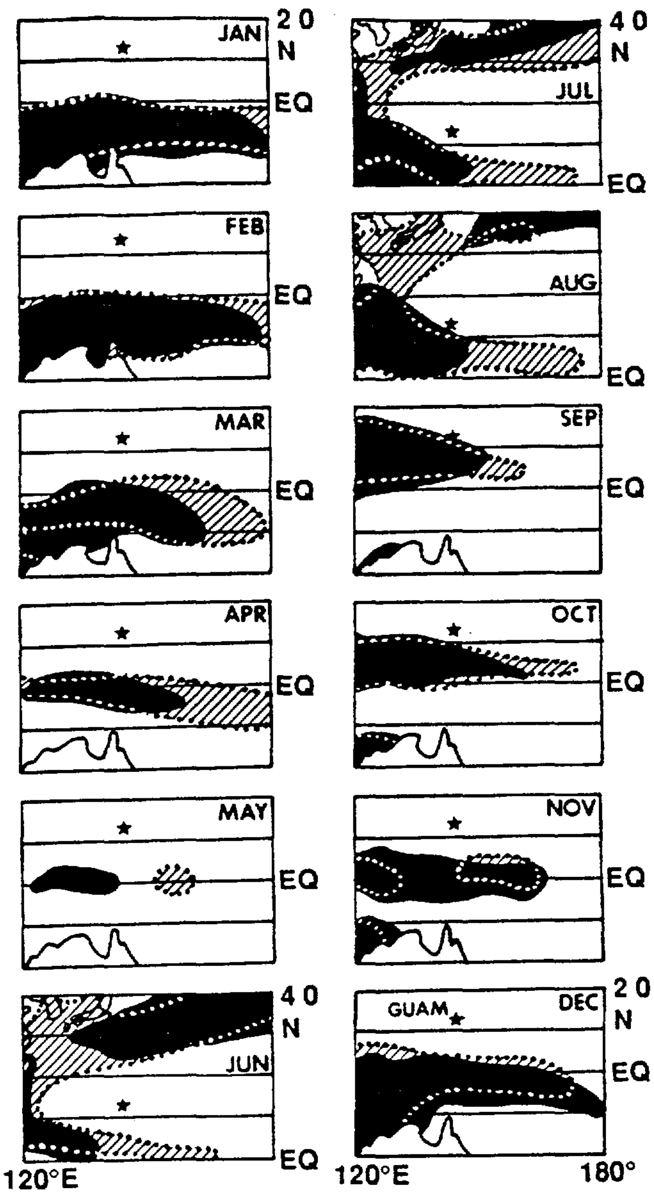


Figure 3-4 Comparison between climatological (black) and analyzed (hatched) mean monthly winds with a westerly component for the western North Pacific in 1993. For June, July, and August the area of coverage is shifted northward to include the subtropics of the North Pacific. For reference, the star indicates the location of Guam. The outline of Australia appears in the lower left of each panel except for June, July, and August where the Korean Peninsula and Japan appear in the upper left. The climatology is adapted from Sadler *et al.*, 1987. The 1993 monthly mean winds were adapted from Australian Bureau of Meteorology, 1993.

Partly as a consequence of many low-latitude (south of 10°N) formations and subsequent westward tracks, the Philippine Islands and Vietnam were impacted by a large number of tropical cyclones. The 18 tropical cyclones of the western North Pacific during 1993 making landfall in the Philippine Islands was a record.

Low-level westerly wind flow along the equator, bounded by near-equatorial troughs in the Northern Hemisphere and Southern Hemisphere, was a persistent wind pattern (hereafter to be referred to as the twin-trough pattern) in the tropical western Pacific from late February through mid-July 1993. This wind pattern is ideal for the development of equatorial westerly wind bursts (Luther et al., 1983; Keen, 1988), and also for the formation of tropical cyclone twins symmetrical with respect to the equator (Dean, 1954; Keen, 1982; Lander, 1990) (see Figure 3-6a). This wind pattern may also feature the simultaneous occurrence of tropical cyclones in both the northern and southern hemispheres which are not symmetrical with respect to the equator, and which may not be at the same stage of development (Figure 3-6b). According to Lander (1990), an equatorial westerly wind burst is a necessary, but not always sufficient, precondition for the formation of tropical cyclone twins.

The first six tropical cyclones of 1993 — Tropical Depression 01W, Irma (02W), Tropical Depression 03W, Tropical Depression 04W, Jack (05W), and Koryn (06W) — all formed in the near-equatorial trough in a large-scale wind and cloud pattern similar to Figure 3-6a or 3-6b. During March, the first named tropical cyclone of the year in the western North Pacific, Irma (02W), formed in association with a westerly wind burst; and, along with Roger (22P), was a classical case of tropical cyclone twins symmetrical with respect to the equator. During April, Tropical Depression 04W formed in association with another equatorial westerly wind burst, and was accompanied by a southern hemisphere twin that didn't mature. Tropical Depression a.

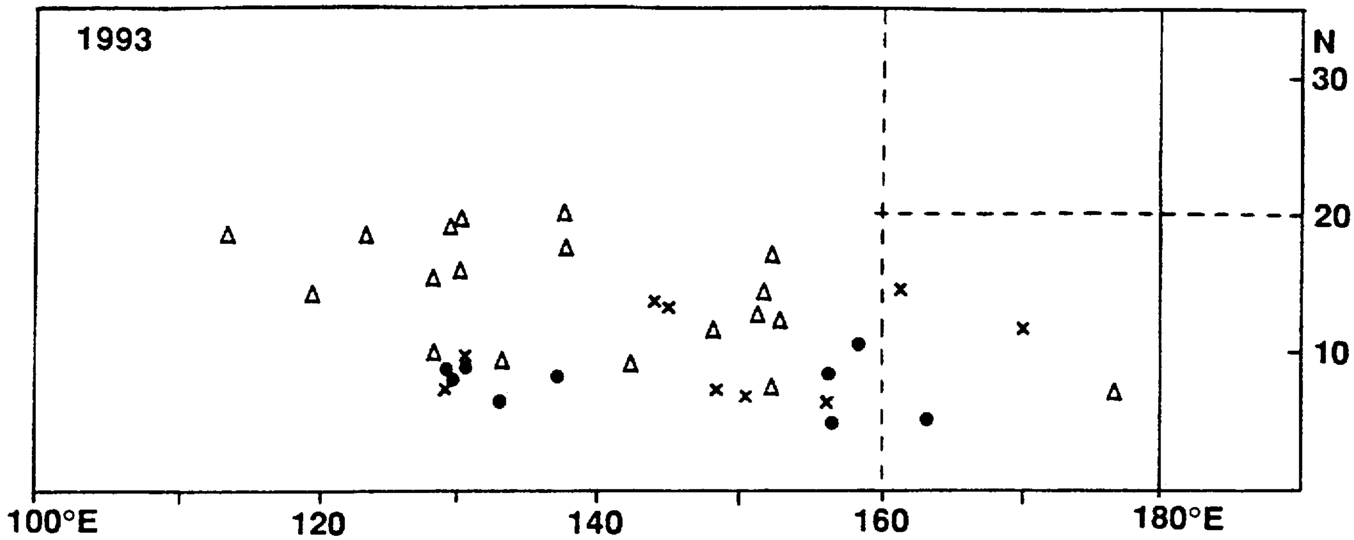


Figure 3-5a Point of formation of significant tropical cyclones in 1993 as indicated by the initial intensity of 25 kt (13 m/sec) on the best track. The symbols indicate: solid dots = 01 January to 15 July; open triangles = 16 July to 15 October; and, X = 16 October to 31 December.

b.

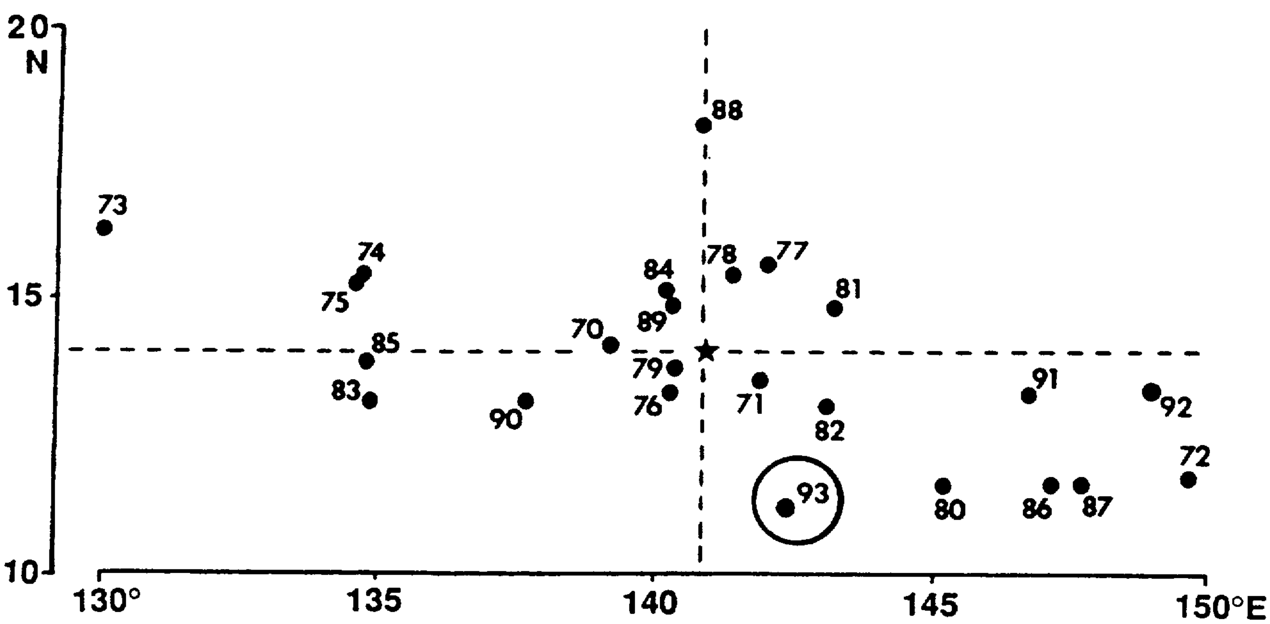


Figure 3-5b Mean annual genesis locations for the period 1970-1993. The 1993's circled location is the southernmost for the 24 years. The star lies at the intersection of the 24-year average latitude and longitude of genisis. For statistical puposes, genesis is defined as the first 25 kt (13 m/sec) intensity on the best track.

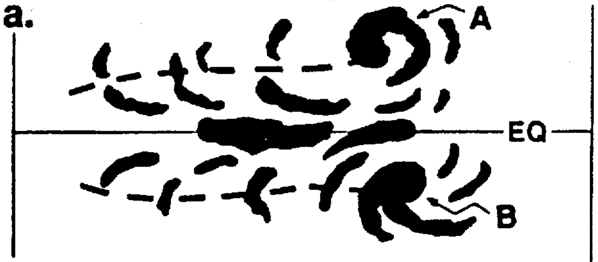


Figure 3-6a Twin-trough pattern associated with a westerly wind burst with tropical cyclones, at points A and B, forming symmetrically with respect to the equator. The axes of the near-equatorial troughs are represented by dashed lines..

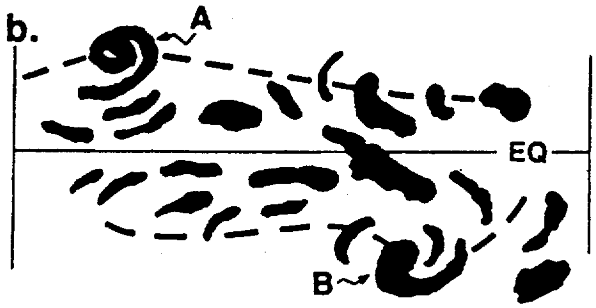


Figure 3-6b Twin-trough pattern with tropical cyclones at points A and B forming without symmetry with respect to the equator.

04W was remarkable for its long westward track, and for its inability to intensify beyond 30 kt (15 m/sec). For several days, the depression was forecast to intensify into a tropical storm but it never did. Jack (05W) formed in the near-equatorial trough of the Northern Hemisphere a few days after Adel (27P) had formed in the twin near-equatorial trough of the Southern Hemisphere in a large-scale low-level flow pattern similar to that shown in Figure 3-6b. During mid June, Koryn (06W) formed at a very low latitude (4°N) in a low-level flow pattern which, yet again, featured equatorial westerlies bounded by twin near-equatorial troughs.

During late June, the large-scale flow pattern, which had resembled the flow patterns shown in Figure 3-6 a and b nearly continuously since February, changed so as to resemble more closely the long-term mean wind field. In this new regime, a weak monsoon trough extended from southeast Asia into the Philippine Sea, and from there eastward into the Caroline Islands. The three tropical cyclones following Typhoon Koryn — Tropical Depression 07W, Lewis (08W), and Marian (09W) — generated in this monsoon trough (see Figure 3-7).

Nathan (10W), formed in the eastern Caroline Islands, was the last tropical cyclone in this monsoon trough as the next major readjustment of the large-scale flow pattern in the tropics of the western North Pacific occurred in late July with the formation of a monsoon gyre in the Philippine Sea. As Nathan moved west-northwestward, a large monsoonal cloud band formed in the Philippine Sea in association with lowering sea-level pressure there. Nathan turned northward as it neared the monsoonal cloud band. This cloud band then became oriented SW-NE and was collocated with a band of 25-35 kt (13-18 m/sec) low-level southwesterly winds on the southeastern periphery of a large low-pressure area, a monsoon gyre, over the Philippine Sea. Nathan accelerated northward to a landfall on Japan. Subsequently, as the monsoon gyre moved steadily westward, two very small tropical cyclones, Ofelia(11W) and Percy (12W), formed in quick succession at the northern end of the monsoon cloud band of the monsoon gyre and moved on north-oriented tracks over southwestern Japan. By the last day of July, the monsoon gyre had been absorbed into the large-scale low-pressure area over eastern Asia.

Also during the last week of July, as the low-pressure area associated with the monsoon gyre moved westward toward east Asia, pressures began to fall in Micronesia, and the monsoon trough extended from the Caroline Islands eastward to the international date line. During the first week of August (Figure 3-8), Typhoons Robyn (13W) and Steve (14W) formed in this monsoon trough. Robyn became a large-sized typhoon which recurved and hit southwestern Japan. During the last two weeks of August, Hurricane Keoni (01C) moved across the

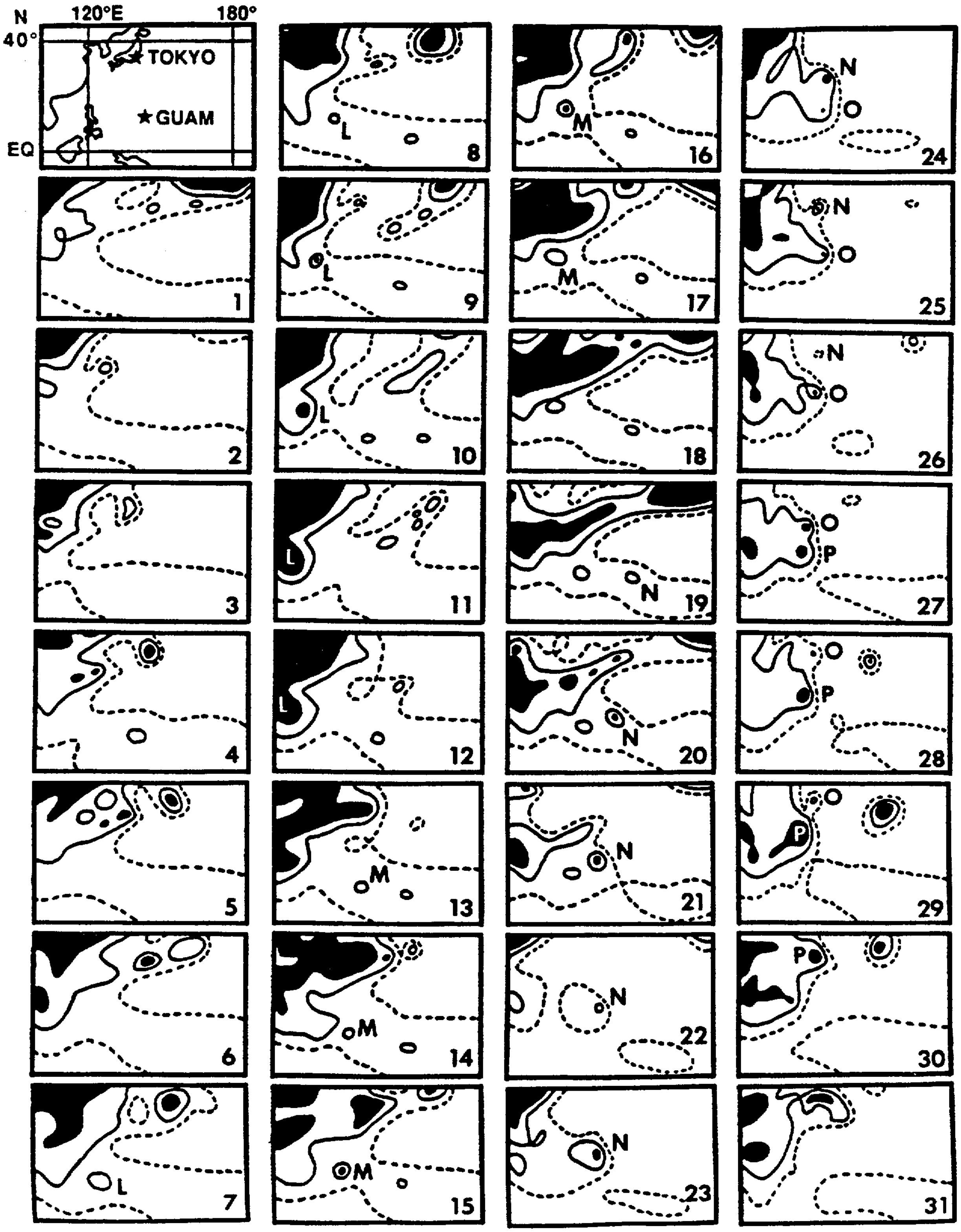


Figure 3-7 Western North Pacific sea-level pressure analyses for July 1993. Map panels are for 0600Z for the date indicated in the lower right of each panel. A geographic reference appears as the upper left panel. Contours (01-21 July): outer dashed line = 1010 mb; solid line = 1008 mb; black ≤ 1004 mb. Contours (22-31 July): outer dashed line = 1008 mb; solid line = 1006 mb; and black area ≤ 1002 mb. Named tropical cyclones: L = Lewis (08W), M = Marian (09W), N = Nathan (10W), O = Ofelia (11W), and P = Percy (12W).

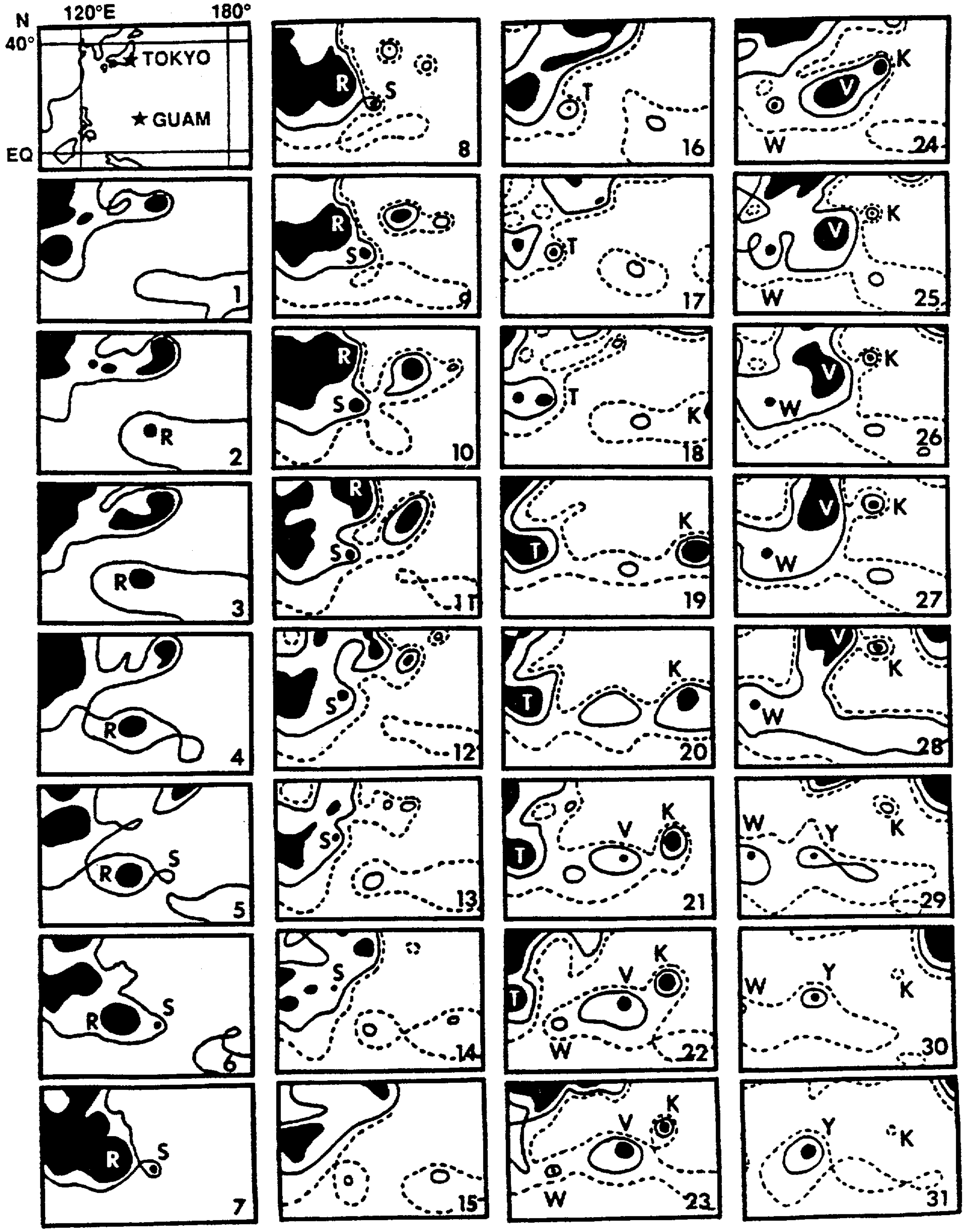


Figure 3-8 Western North Pacific sea-level pressure analyses for August 1993. Map panels are for 0600Z for the date indicated in the lower right of each panel. A geographic reference appears as the upper left panel. Contours: outer dashed line = 1010 mb; solid line = 1008 mb; black ≤ 1004 mb. Named tropical cyclones: R = Robyn (13W), S = Steve (14W), T = Tasha (16W), K = Keoni (01C), and V = Vernon (17W), W = Winona (18W), Y = Yancy.

international date line from the central Pacific into the western Pacific — was renamed Typhoon Keoni — and meandered for two weeks over subtropical waters north of Wake Island. During the last two weeks of August and into the first week of September, the monsoon trough of the western North Pacific became very active as seven tropical cyclones — Tasha (16W), Vernon (17W), Winona (18W), Yancy (19W), Zola (20W), Abe (21W) and Becky (22W) — formed in it. Three of these tropical cyclones — Vernon (17W), Yancy (19W), and Zola (20W) — made landfall in Japan. During the last week of July through the first week of September, a concentrated assault of Japan by tropical cyclones took place. Seven of the period's 12 tropical cyclones, beginning with Nathan (10W) during the last week of July and ending with Zola (20W) during the first week of September, made landfall there.

Five of seven tropical cyclones occurring from late September to midOctober — Cecil (23W), Ed (25W), Flo (26W), Gene (27W) and Hattie (29W) — recurved into the mid-latitudes of the North Pacific well offshore of Japan. After Hattie, which formed as a very large monsoon depression then recurved into mid-latitudes in late October, all subsequent tropical cyclones formed at low-latitude (near or south of 10°N) and traveled on westward tracks which kept them in tropical latitudes. Six of the final eight tropical cyclones of 1993, beginning with Ira (30W) and ending with Nell (37W), made landfall in the Philippine Islands.

In early November, three tropical cyclones — Jeana (31W), Tropical Depression 32W, and Tropical Depression 33W — developed, but failed to mature. Jeana reached 50 kt (26 m/sec) for only a brief time after recurvature. Jeana was one of a small subset of all tropical cyclones that reached peak intensity after recurvature. Tropical Depression 32W and Tropical Depression 33W both had long histories as disturbances. Four Tropical Cyclone Formation Alerts were issued on the disturbance that eventually became Tropical Depression 32W. All subsequent tropical cyclones — Kyle (34W), Lola (35W), Manny (36W), and Nell (37W) — became typhoons. The last tropical cyclone of November, Kyle (34W) developed just to the northeast of Tropical Depression 32W. Both systems moved into the southern Philippine Islands in tandem. Tropical Depression 32W dissipated there. Kyle crossed the Philippine Islands into the South China Sea, moved toward Vietnam, and rapidly intensified.

During December, Lola (35W) formed in an active near-equatorial trough that ultimately produced a series of three late-season typhoons — Lola (35W), Manny (36W) and Nell (37W). After developing in the western Marshall Islands, Lola slowly intensified, and over a week later, slammed into the heavily populated Bicol region of southern Luzon. Upon leaving the Philippine Islands, Lola headed toward the southwest, rapidly re-intensified — a rare event in the South China Sea — and crashed into southern Vietnam. Three days after Lola developed, Manny began to form in the eastern Caroline Islands along the axis of the near-equatorial trough. Like Lola, Manny raced across the Micronesian Islands at 20 kt (35 km/hr) and slowly intensified. Unlike Lola, Manny slowed to the east of Luzon, and appeared to be very close to recurving; instead it executed an anticyclonic loop, then came out of the loop on a southwestward track and rapidly intensified en route to the Philippine Islands. Manny weakened to a weak tropical storm in the South China Sea, moved to the southern Gulf of Thailand, and dissipated over the Malay Peninsula. A few days later, Nell (37W) began to develop in the eastern Caroline Islands, about 300 nm (555 km) west of where Manny had developed. Nell crossed the Philippine Sea at an average speed of 15 kt (28 km/hr), slowly intensifying. Fortunately, Nell was a very small typhoon when it crashed into northern Mindanao, turned to the northwest, and crossed the Visayan Islands of Bohol, Cebu, Iloilo, and Panay. After exiting the Philippine Islands, Nell ran into strong upper-level shear, turned to the southwest, and dissipated over water in the southeastern South China Sea. The long westward tracks of the late-season tropical cyclones were associated with an anchored long-wave trough over western and central China and a high zonal index of the mid-latitude westerlies. The western North Pacific basin continued to be active right up to the end of the calendar year 1993; on 30 December 1993, Nell (37W) — the last of three Typhoons in December — dissipated in the South China Sea.

In summary, an illustration of all the tropical cyclone activity in the western North Pacific and North Indian Oceans is provided in Figure 3-9. Table 3-3 includes: a climatology of typhoons, tropical storms and typhoons for the western North Pacific for the period 1945-1959 and 1960-1993; and summary of warning days. Table 3-4 is a summary of the TCFA's for the Western North Pacific for 1976-1993. Composite best tracks for the North West Pacific Ocean tropical cyclones are provided for the periods: 1 January to 26 July (Figure 3-10), 24 July to 10 September (Figure 3-11), 7 September to 5 November (Figure 3-12), and 7 November to 31 December (Figure 3-13).

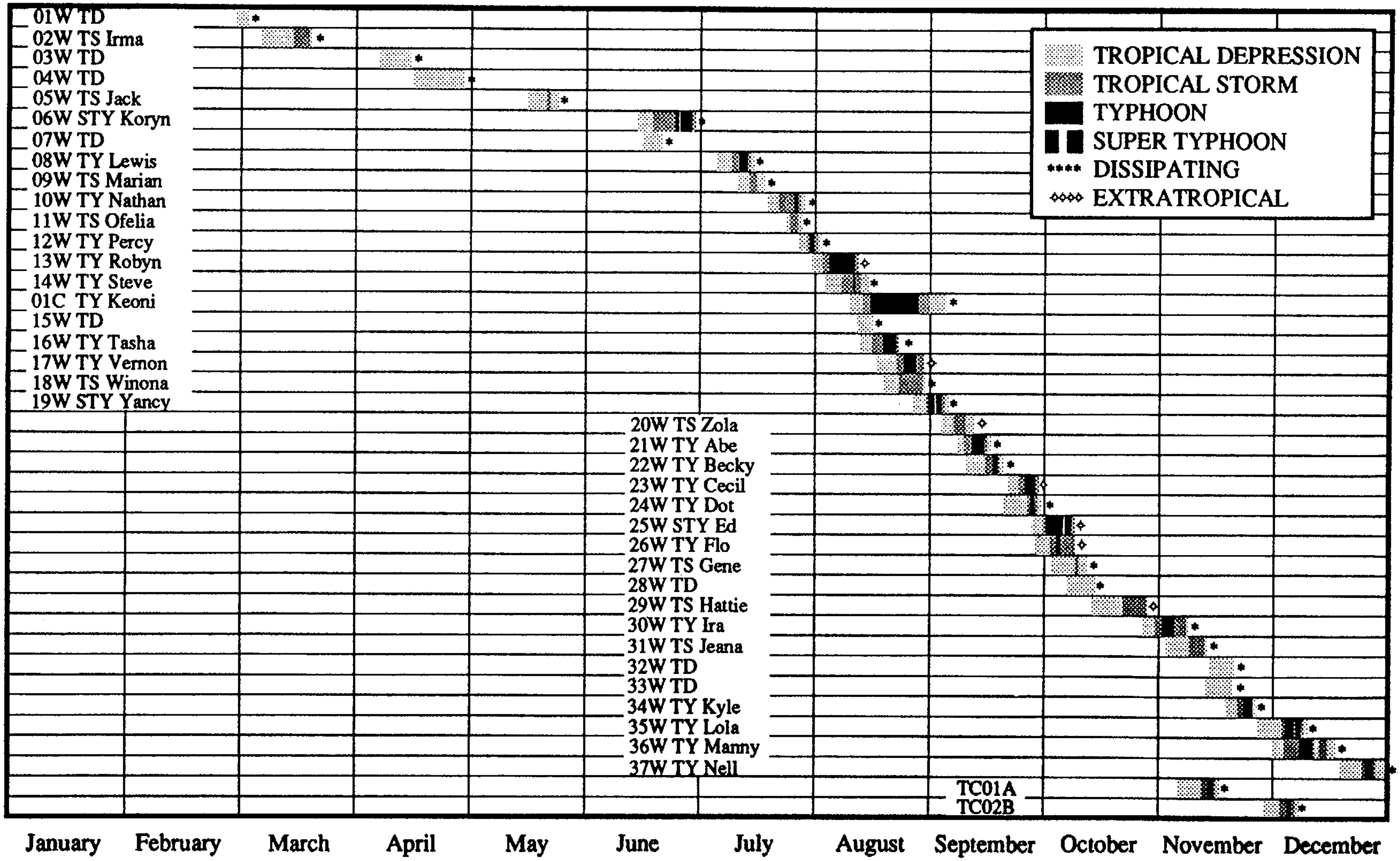


Figure 3-9 Chronology of western North Pacific and North Indian Ocean tropical cyclones for 1993.

Table 3-3 WESTERN NORTH PACIFIC TROPICAL CYCLONES

TYPHOONS

(1945 - 1959)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.3	0.1	0.3	0.4	0.7	1.0	2.9	3.1	3.3	2.4	2.0	0.9	16.4
CASES	5	1	4	6	10	15	29	46	49	36	30	14	245

(1960 - 1993)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.3	0.1	0.2	0.4	0.7	1.1	2.7	3.3	3.3	3.2	1.8	0.7	17.8
CASES	10	2	7	15	24	38	93	112	112	108	61	23	605

TROPICAL STORMS AND TYPHOONS

(1945 - 1959)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.4	0.1	0.5	0.5	0.8	1.6	2.9	4.0	4.2	3.3	2.7	1.2	22.2
CASES	6	2	7	8	11	22	44	60	64	49	41	18	332

(1960 - 1993)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
MEAN	0.6	0.3	0.5	0.6	1.1	1.9	4.2	5.5	5.0	4.2	2.8	1.2	27.7
CASES	19	9	16	22	37	63	142	186	169	144	94	41	942

NUMBER OF CALENDAR WARNING DAYS 181
NUMBER OF CALENDAR WARNING DAYS WITH TWO TROPICAL CYCLONES 49
NUMBER OF CALENDAR WARNING DAYS WITH THREE TROPICAL CYCLONES 12
NUMBER OF CALENDAR WARNING DAYS WITH FOUR TROPICAL CYCLONES 3

Table 3-4 TROPICAL CYCLONE FORMATION ALERTS FOR THE WESTERN NORTH PACIFIC OCEAN 1976-1993

YEAR	INITIAL TCFAS	TROPICAL CYCLONES WITH TCFAS	TOTAL TROPICAL CYCLONES	FALSE ALARM RATE*	PROBABILITY OF DETECTION
1976	34	25	25	26%	100%
1977	26	20	21	23%	95%
1978	32	27	32	16%	84%
1979	27	23	28	15%	82%
1980	37	28	28	24%	100%
1981	29	28	29	3%	96%
1982	36	26	28	28%	93%
1983	31	25	25	19%	100%
1984	37	30	30	19%	100%
1985	39	26	27	33%	96%
1986	38	27	27	29%	100%
1987	31	24	25	23%	96%
1988	33	26	27	21%	96%
1989	51	32	35	37%	91%
1990	33	30	31	9%	97%
1991	37	29	31	22%	94%
1992	36	32	32	20%	100%
1993	50	35	38	30%	92%
(1976-1993)					
MEAN:	35.4	27.4	28.8	23%	95%
TOTALS:	637	493	519		

* The false alarm rate is the difference between the number of initial TCFA's and the number of Tropical Cyclones with TCFA's divided by the number of inital TCFA's and is expressed as a percentage.

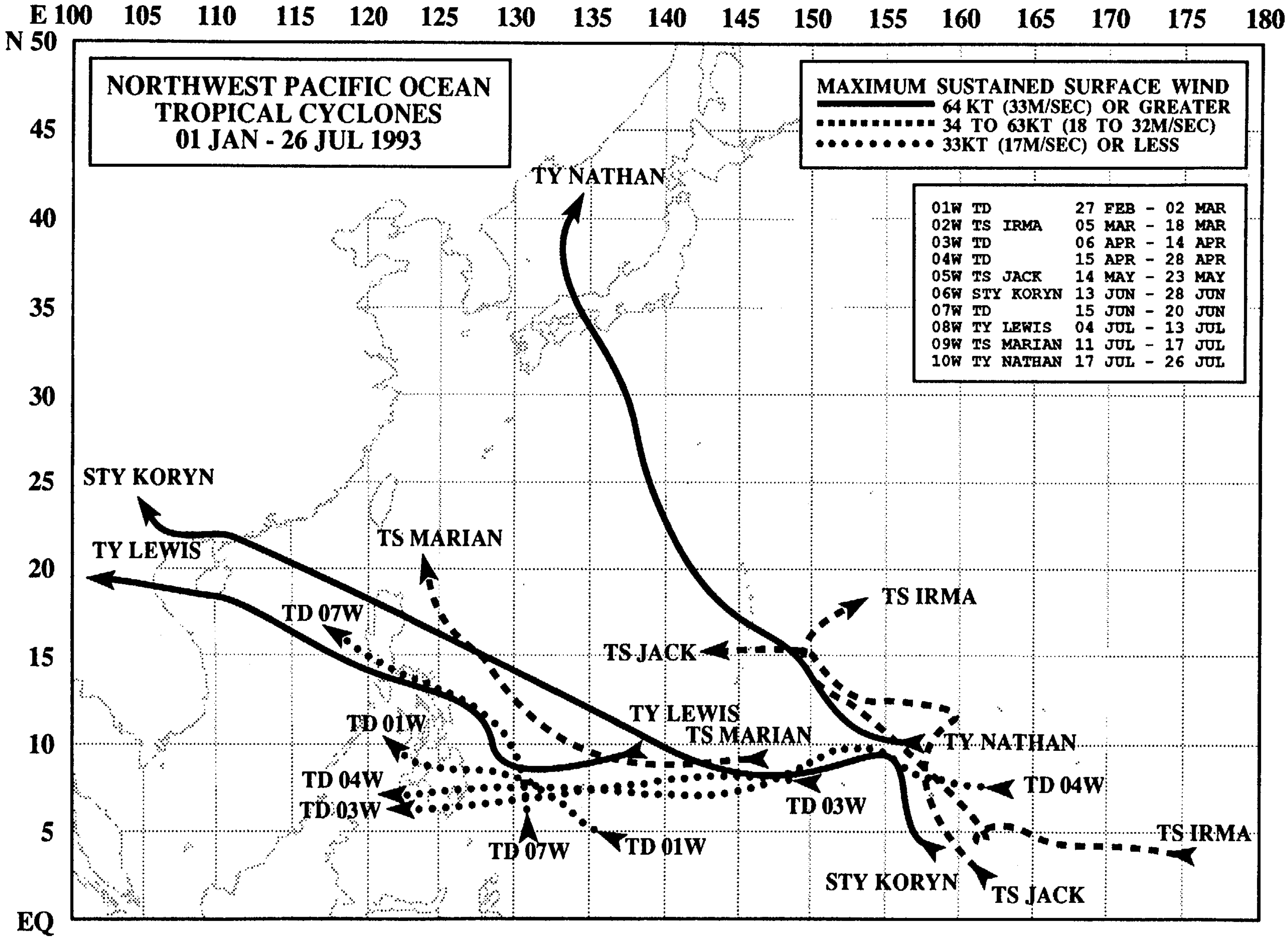


Figure 3-10 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 1 January to 26 July 1993.

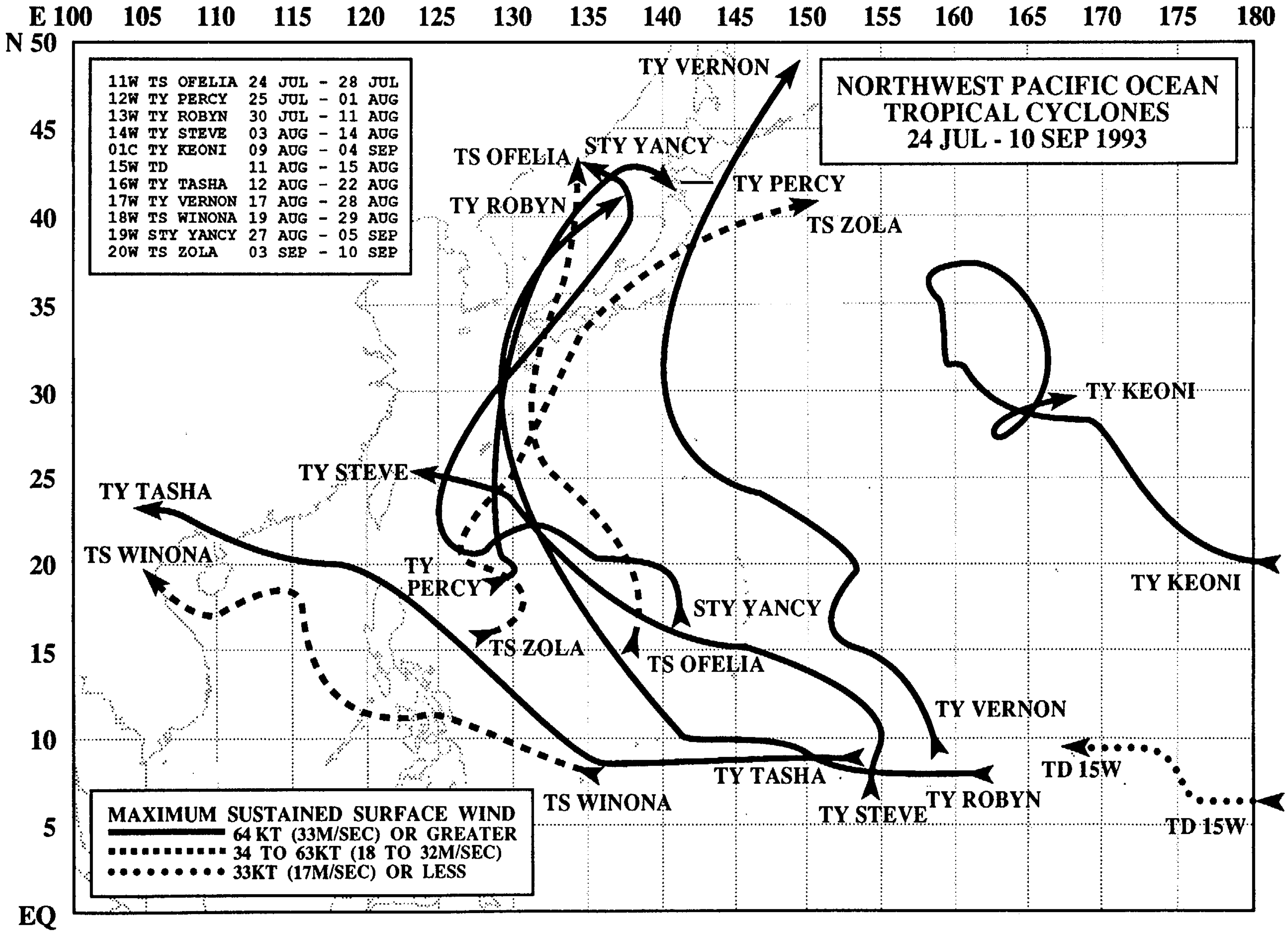


Figure 3-11 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 24 July to 10 September 1993.

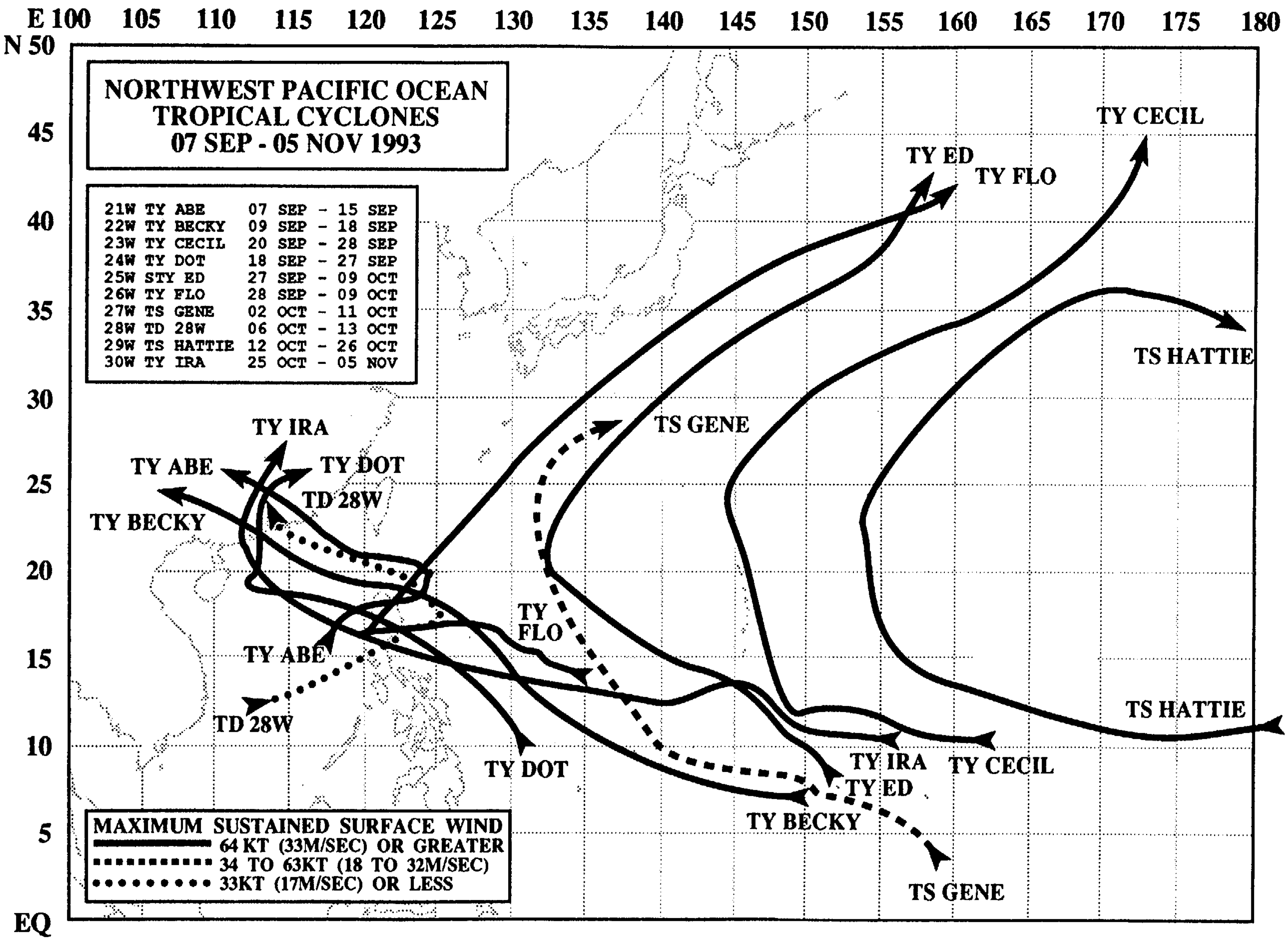


Figure 3-12 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 7 September to 5 November 1993.

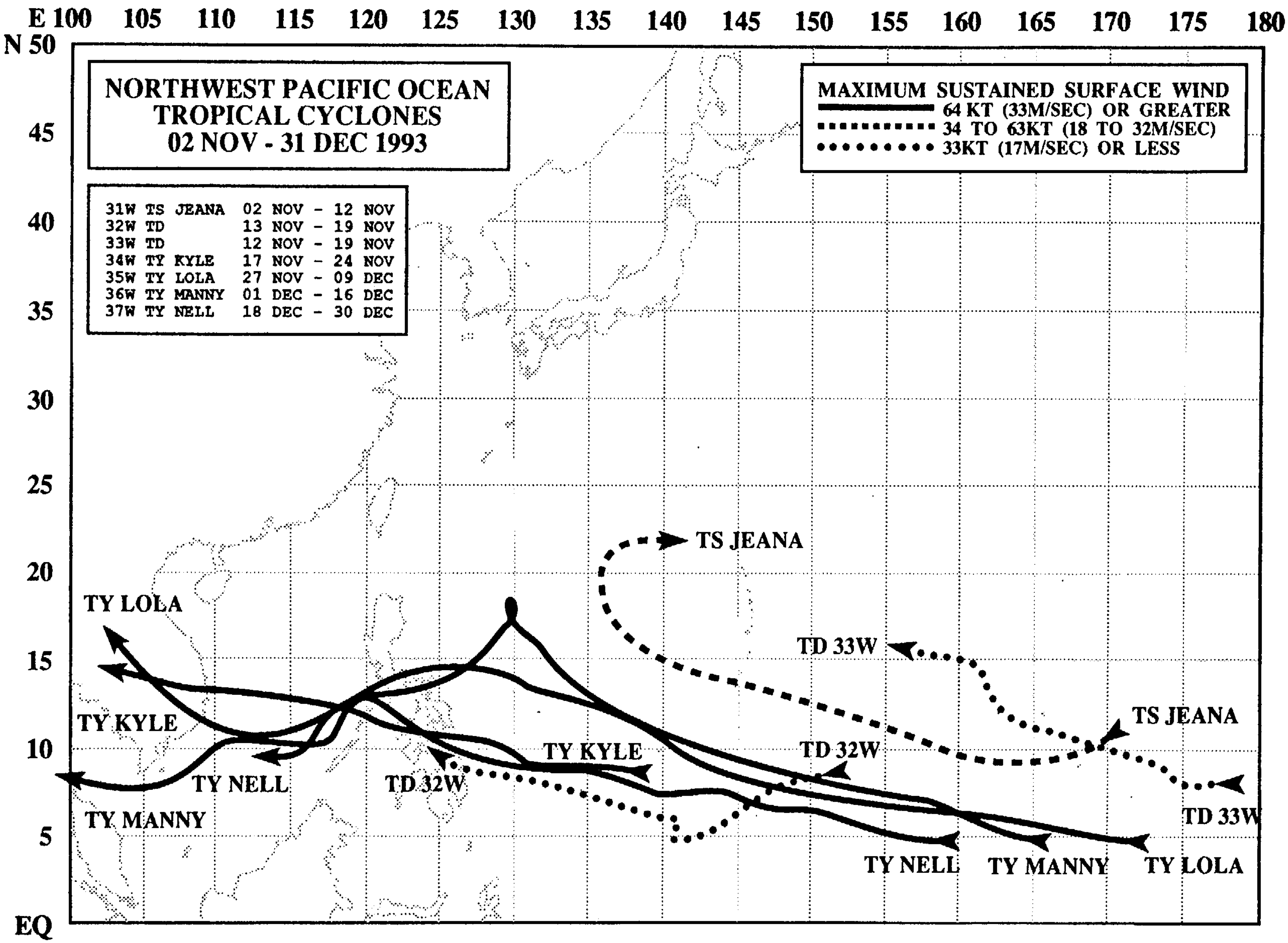
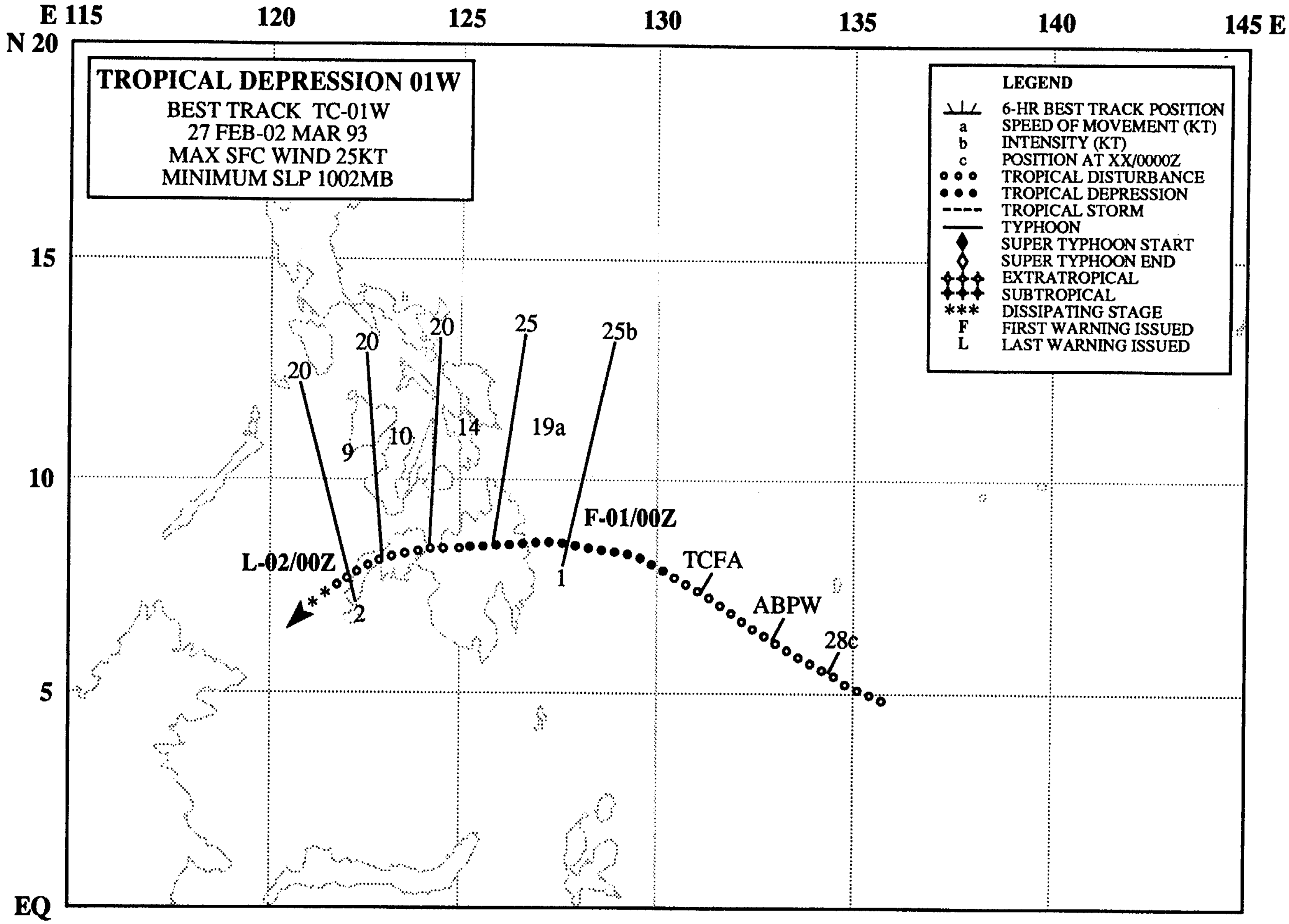


Figure 3-13 Composite best tracks for the North West Pacific Ocean tropical cyclones for the period 2 November to 31 December 1993.


TROPICAL DEPRESSION 01W
BEST TRACK TC-01W
27 FEB-02 MAR 93
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135
140
145 E
N 20
15
10
5
EQ
20
20
20
25
25b
9
10
14
19a
F-01/00Z
L-02/00Z
TCFA
ABPW
28c
1
2

TROPICAL DEPRESSION 01W

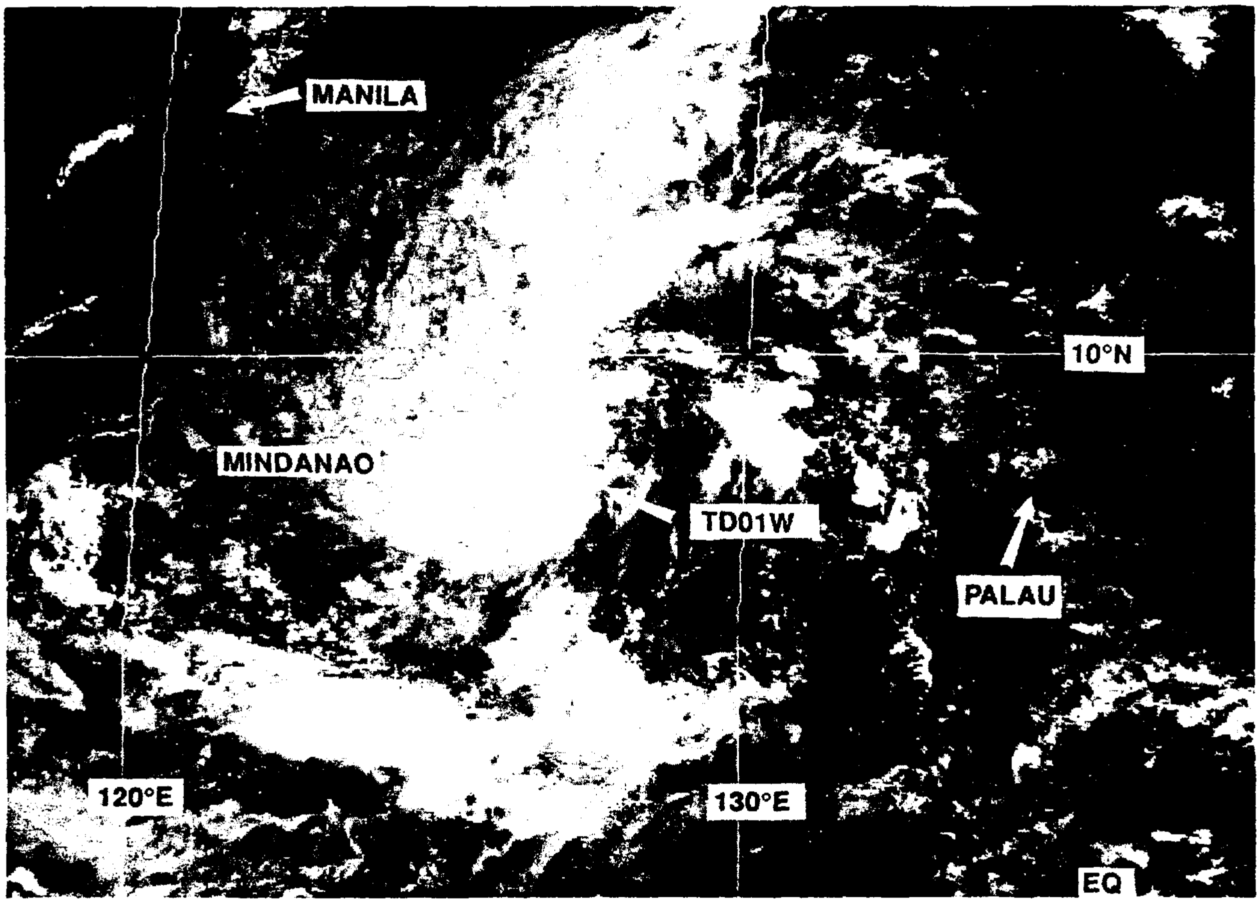


Figure 3-01-1 TD 01W approaches the island of Mindanao (010030Z March visual GMS imagery).

I. HIGHLIGHTS

The first tropical cyclone to occur in the western North Pacific Ocean in 1993, and the first of two significant tropical cyclones to occur in March, Tropical Depression 01W was a short-lived system that required only five warnings. It began as a tropical disturbance in the near-equatorial trough southeast of Palau in the western Caroline Islands and ended by dissipating over the mountainous terrain of Mindanao Island in the Philippines.

II. CHRONOLOGY OF EVENTS

February

280600Z - Tropical Depression 01W was first mentioned on the Significant Tropical Weather Advisory based on convection flaring up over a preexisting low-level cyclonic circulation.

281230Z - Persistent convection near the circulation center led to the issuance of a Tropical Cyclone Formation Alert.

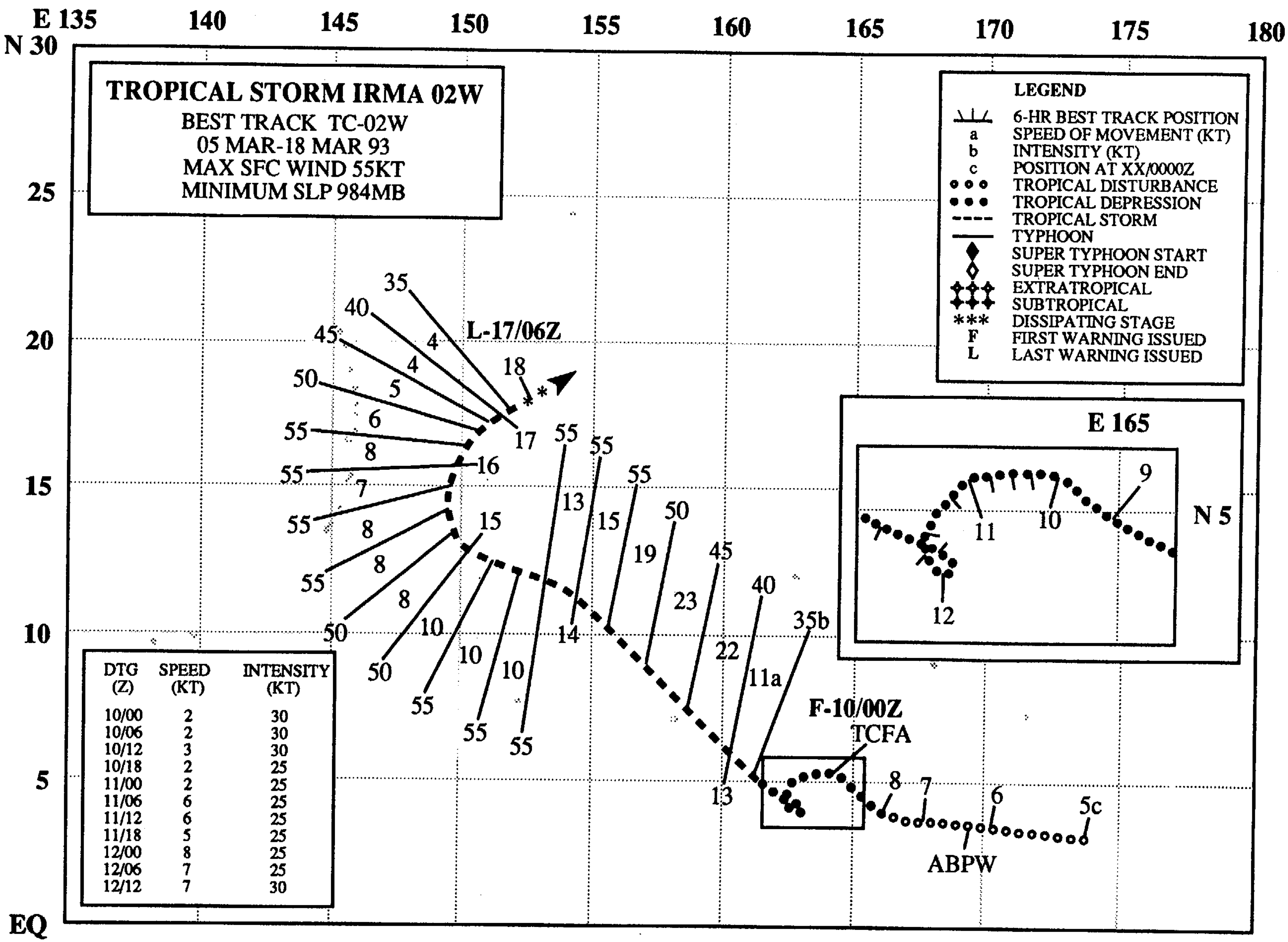
March

010000Z - The initial warning was released based on the first visual satellite image of the day, which showed improved convective organization and a satellite intensity estimate of 25 kt (13 m/sec) (Figure 3-01-1).

020000Z - The final warning was issued following rapid weakening over the rugged island of Mindanao in the southern Philippine Islands.

III. IMPACT

Heavy rains near the Mayon volcano, 180 nm (335 km) southeast of Manila, caused mudslides. No injuries or deaths were reported.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
10/00	2	30
10/06	2	30
10/12	3	30
10/18	2	25
11/00	2	25
11/06	6	25
11/12	6	25
11/18	5	25
12/00	8	25
12/06	7	25
12/12	7	30

TROPICAL STORM IRMA (02W)

I. HIGHLIGHTS

The first tropical cyclone to reach tropical storm intensity in the western North Pacific Ocean during 1993, Irma formed from a strong equatorial westerly wind burst which also generated a twin tropical cyclone in the Southern Hemisphere - Tropical Cyclone Roger (22P). After moving toward the southern Mariana Islands for 10 days, Irma briefly threatened Guam, moved northeastward and dissipated.

II. CHRONOLOGY OF EVENTS

March

060600Z - The disturbance was first mentioned on the Significant Tropical Weather Advisory south of the Marshall Islands based upon synoptic reports which indicated a weak low-level circulation near the eastern end of extensive cloudiness associated with the west wind burst.

092330Z - The consolidation of convection near the low-level circulation center led to issuance of a Tropical Cyclone Formation Alert (TCFA). Post analysis of satellite and synoptic data indicate Irma attained tropical depression status two days earlier at 080000Z.

100000Z - The first warning on Tropical Depression 02W closely followed the TCFA when a 30 kt (15 m/sec) surface wind report was received from Kosrae (WMO 91356).

121800Z - As the twin systems moved farther apart, Tropical Depression 02W was upgraded to Tropical Storm Irma based on a satellite intensity estimate of 35 kt (18 m/sec).

170600Z - The final warning was issued as Irma dissipated in a vertically sheared and stable trade-wind environment.

III. IMPACT

None. However, an accurate recurvature forecast allowed aircraft positioned at Andersen AFB, Guam for Team Spirit 93 to remain in-place.

IV. DISCUSSION

On 08 March 1993, a band of low-level westerlies stretched along the equator from about 120°E to the international date line. These westerlies were confined to very low latitudes by two near-equatorial troughs, one at about 5°N, the other at about 5°S.

At the eastern terminus of the equatorial westerly flow, two weak cyclonic circulations, symmetrical with respect to the equator, had formed (Figure 3-02-1). A ship report of 30 kt (15 m/sec) near the equator at 155°E indicated that an equatorial westerly wind burst had commenced. Three days later, on 10 March, the deep convective cloud -- which had been clustered along the equator (Figure 3-02-2) — began to consolidate into tropical cyclone twins (Figure 3-02-3). (Note: the term, "tropical cyclone twins", implies a symmetry with respect to the equator.) By 13 March, the twin tropical cyclones — Irma in the Northern Hemisphere, and Tropical Cyclone Roger (22P) in the Southern Hemisphere — had become mature tropical cyclones heading westward and poleward into their respective hemisphere. As with other twin-cyclone events, by the time the tropical cyclones had matured, the cloudiness along the equator had collapsed (Lander, 1990). Roger (22P) and Irma continued an unbroken sequence of the occurrence of tropical cyclone twins once every year since 1991: Walt and Lisa, May 1991; Axel and Betsy, January 1992; and, Roger (22P) and Irma, March 1993.

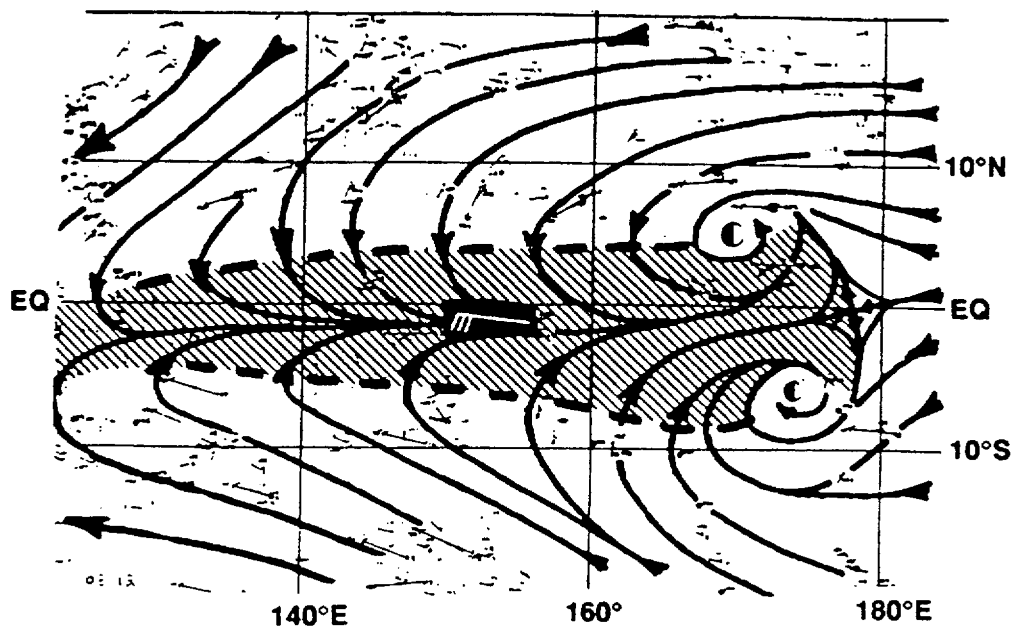


Figure 3-02-1 Streamline analysis of the low-level wind field at 081200Z March. Shaded region shows area of westerly wind flow. The cyclonic circulation centers later become the tropical cyclone twins — Irma and Roger (22P).

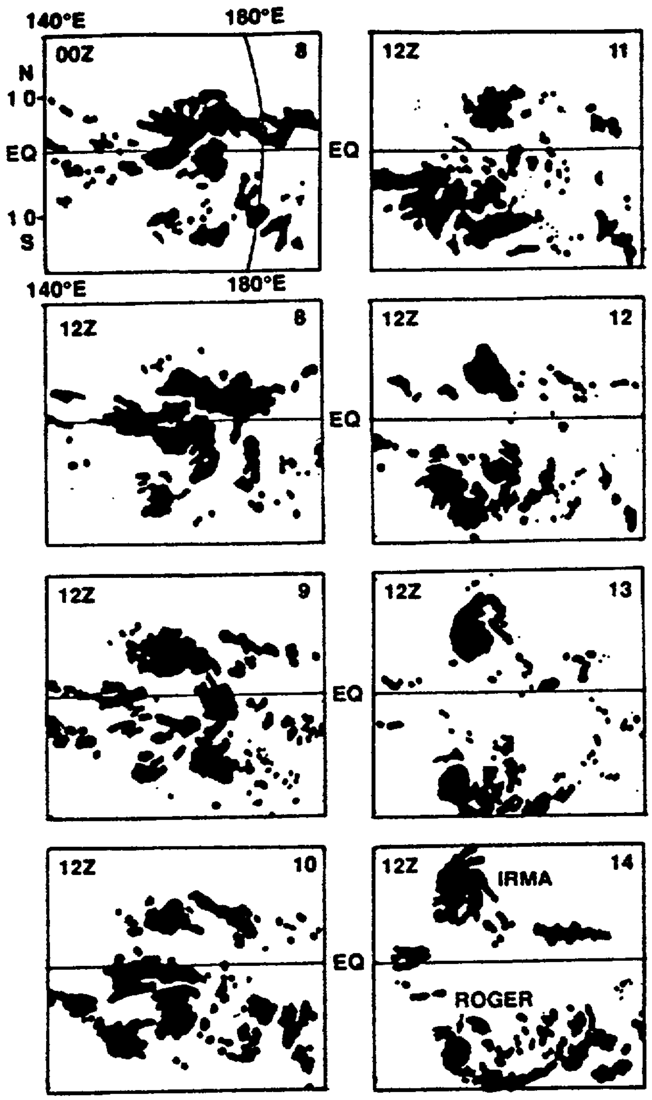


Figure 3-02-2 Cloud silhouettes for the period 8 to 14 March show the development of Irma and Roger (22P).

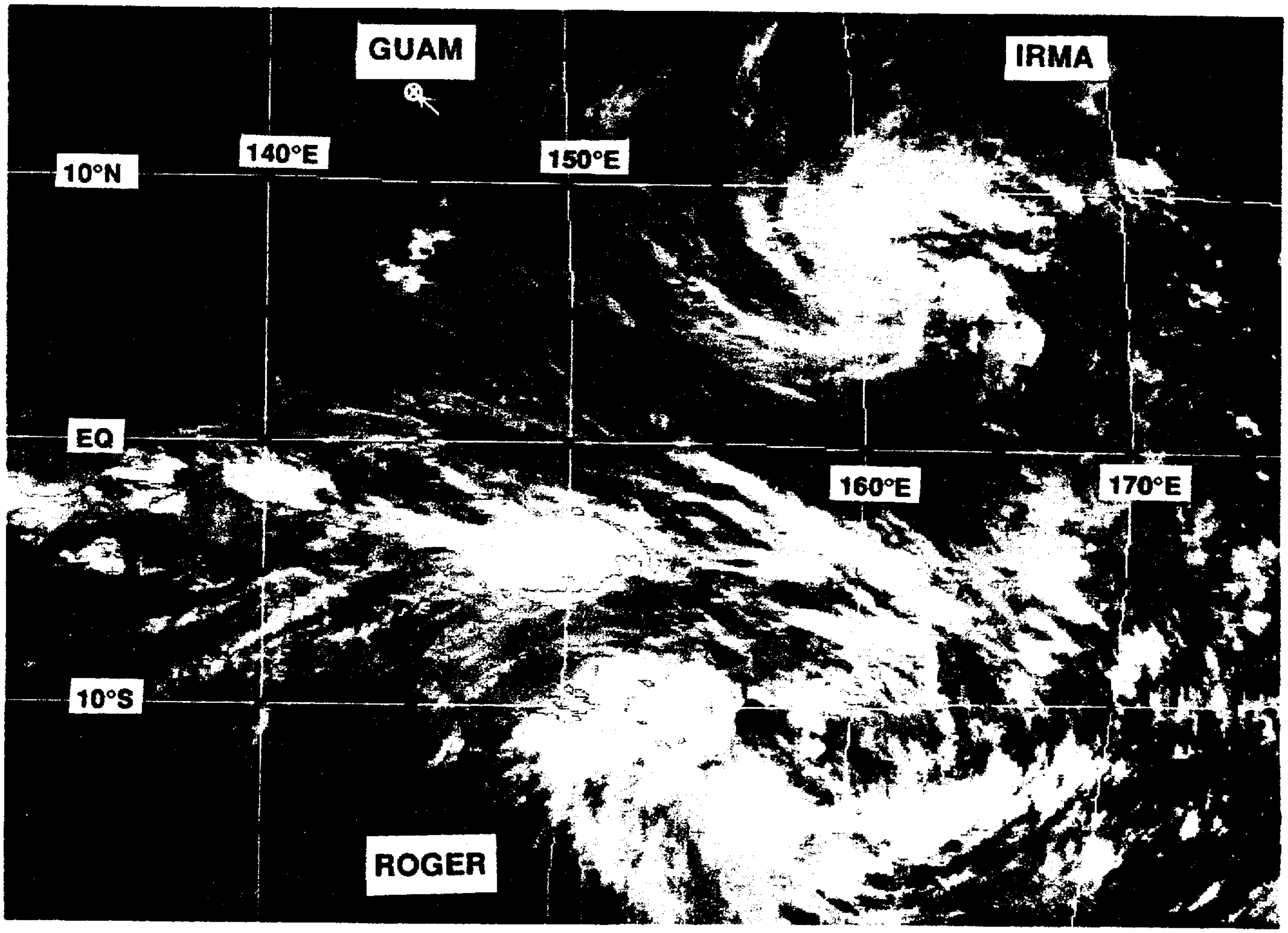
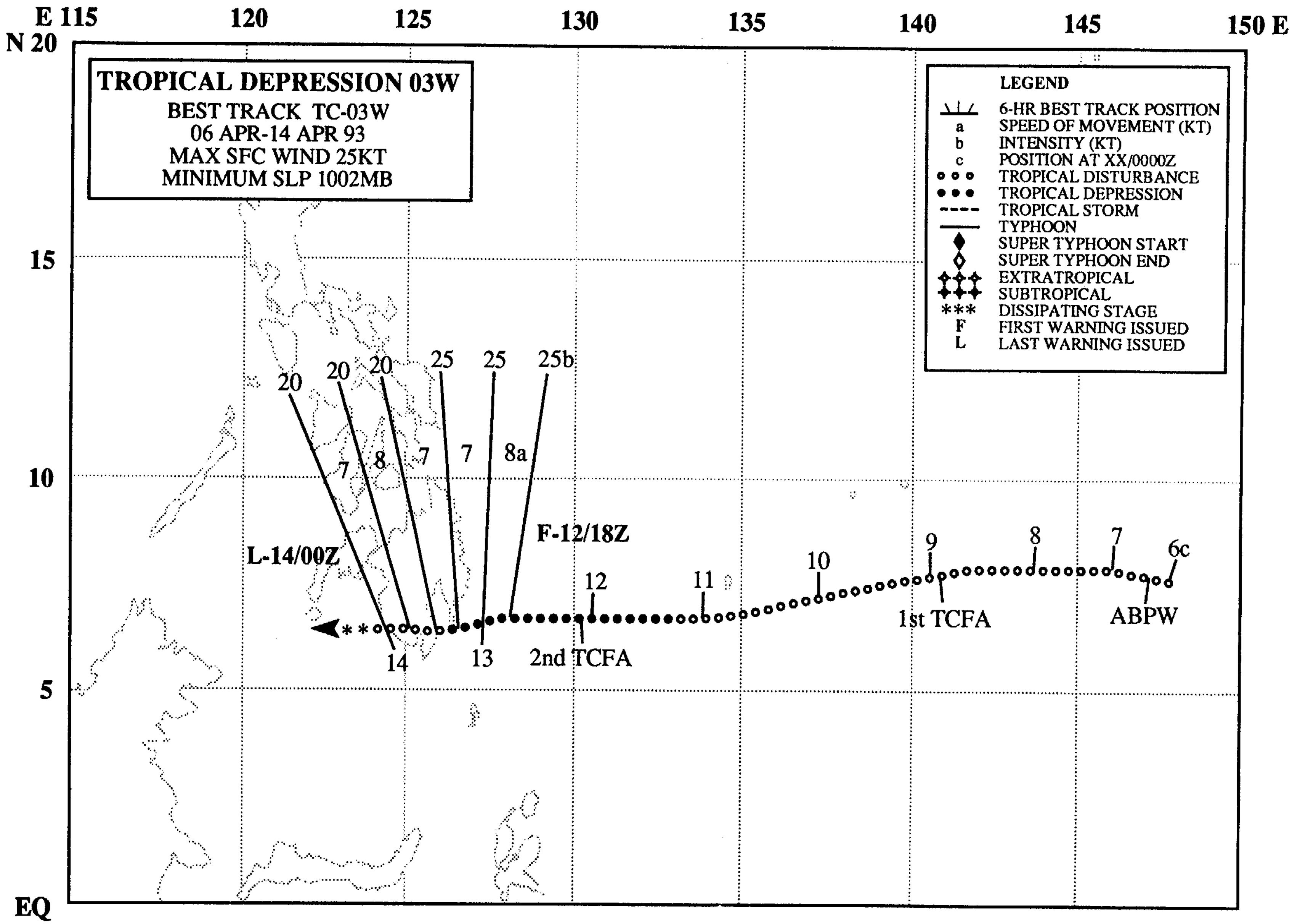


Figure 3-02-3 Tropical cyclone twins Irma and Roger (22P) are shown (120030Z March infrared GMS imagery).


TROPICAL DEPRESSION 03W
BEST TRACK TC-03W
06 APR-14 APR 93
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135
140
145
150 E
N 20
15
10
5
EQ
L-14/00Z
F-12/18Z
20
20
20
25
25
25b
7
8
7
7
8a
14
13
2nd TCFA
12
11
10
9
8
7
6c
1st TCFA
ABPW

TROPICAL DEPRESSION 03W

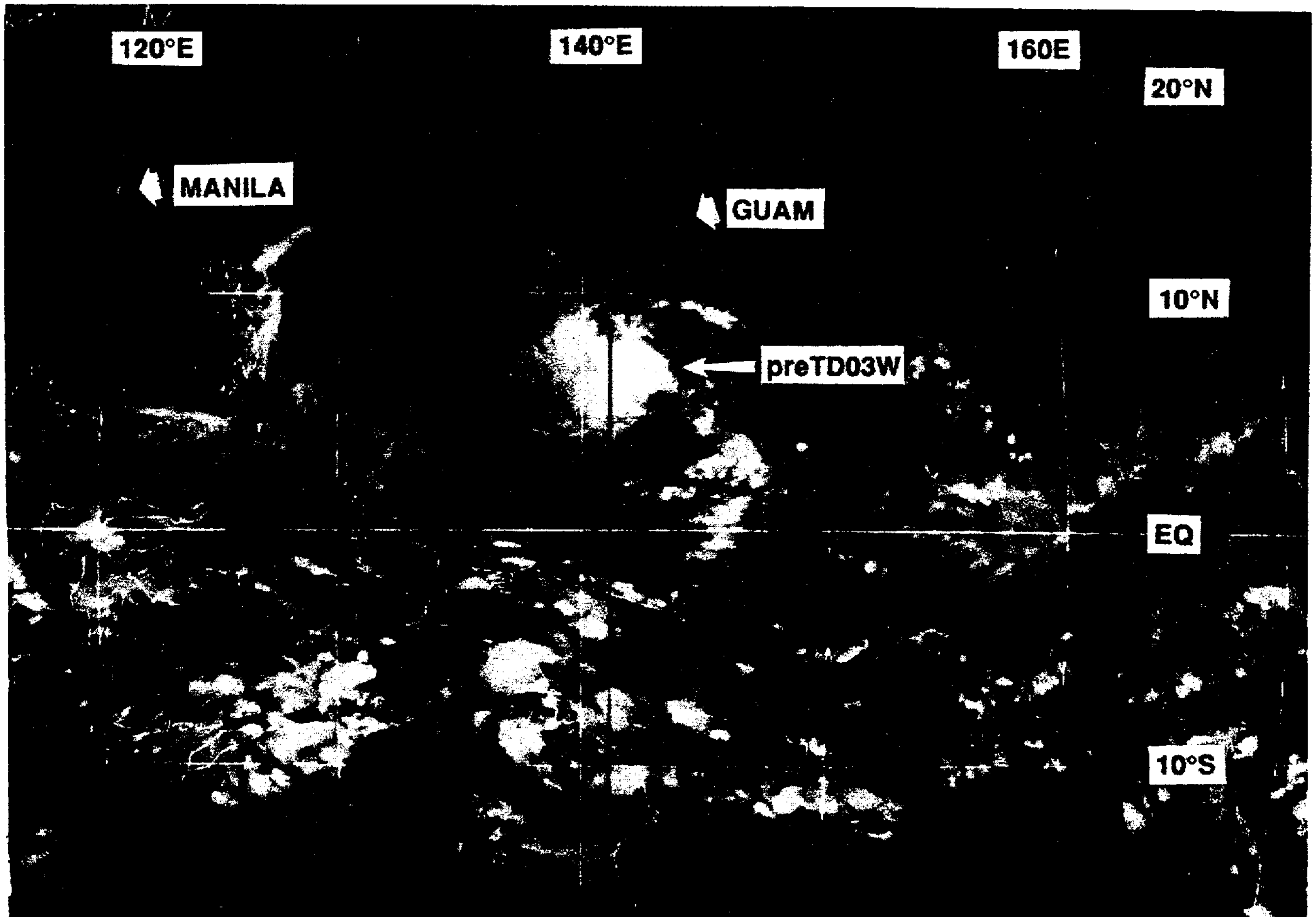


Figure 3-03-1 Convection associated with the tropical disturbance — later TD03W — flares up in early morning hours which is the normal time for the maximum cloudiness (081730Z April infrared GMS imagery).

I. HIGHLIGHTS

The first of two significant tropical cyclones to form in the near-equatorial trough during April, Tropical Depression 03W moved steadily westward, weakened over the island of Mindanao in the southern Philippines, and dissipated.

II. CHRONOLOGY OF EVENTS

April

060600Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection near Chuuk in the eastern Caroline Islands.

082330Z - The consolidation of convection around the low-level circulation center led to the issuance of a Tropical Cyclone Formation Alert (TCFA) (Figure 3-03-1¡).

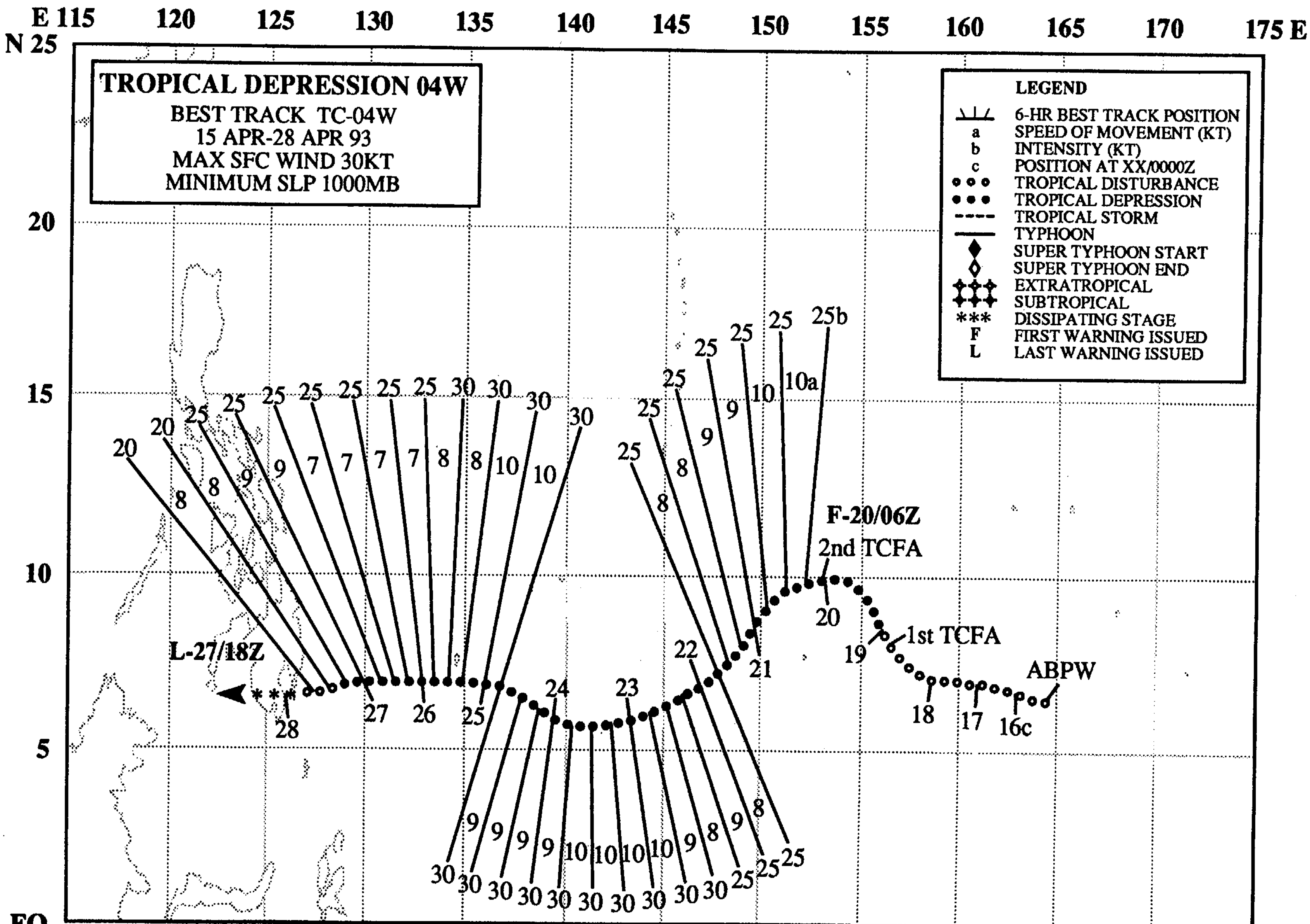
092330Z - The TCFA was canceled due to a steady decrease in convection during the previous 24 hours.

120300Z - A second TCFA was issued based upon increasing convection over the preexisting low-level circulation center.

121800Z - Initial warning was issued on Tropical Depression 03W based on ship synoptic wind reports of 25 kt (13 m/sec).
140000Z - Final warning was issued as Tropical Depression 03W weakened over the rugged island of Mindanao.

III. IMPACT

None.


TROPICAL DEPRESSION 04W
BEST TRACK TC-04W
15 APR-28 APR 93
MAX SFC WIND 30KT
MINIMUM SLP 1000MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135
140
145
150
155
160
165
170
175 E
N 25
20
15
10
5
EQ
F-20/06Z
2nd TCFA
1st TCFA
ABPW
L-27/18Z
25b
10a
16c
17
18
19
20
21
22
23
24
25
26
27
28

TROPICAL DEPRESSION 04W

I. HIGHLIGHTS

A day after Tropical Depression 03W dissipated over Mindanao, Tropical Depression 04W formed in the near-equatorial trough in the Marshall Islands during a period of enhanced cloudiness associated with a westerly wind burst along the equator. Like its predecessor, Tropical Depression 03W, this tropical cyclone tracked westward through the Caroline Islands and over southern Mindanao, where it dissipated (Figure 3-04-1).

II. CHRONOLOGY OF EVENTS

April

150600Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as a broad area of persistent convection within the near-equatorial trough.

181900Z - A significant increase in central convection led to the issuance of a Tropical Cyclone Formation Alert (TCFA).

191900Z - The TCFA was canceled due to a steady decrease in the amount of convection during the previous 24 hours.

200200Z - A second TCFA was issued based upon increasing convection over the low-level circulation center and a 20 kt (10 m/sec) ship report in the vicinity.

200600Z - The first warning was released based upon the persistent of a central cloud feature and satellite intensity estimate of 30 kt (15 m/sec).

271800Z - The final warning was issued as the tropical cyclone dissipated over the island of Mindanao in the Philippines.

III. IMPACT

None.

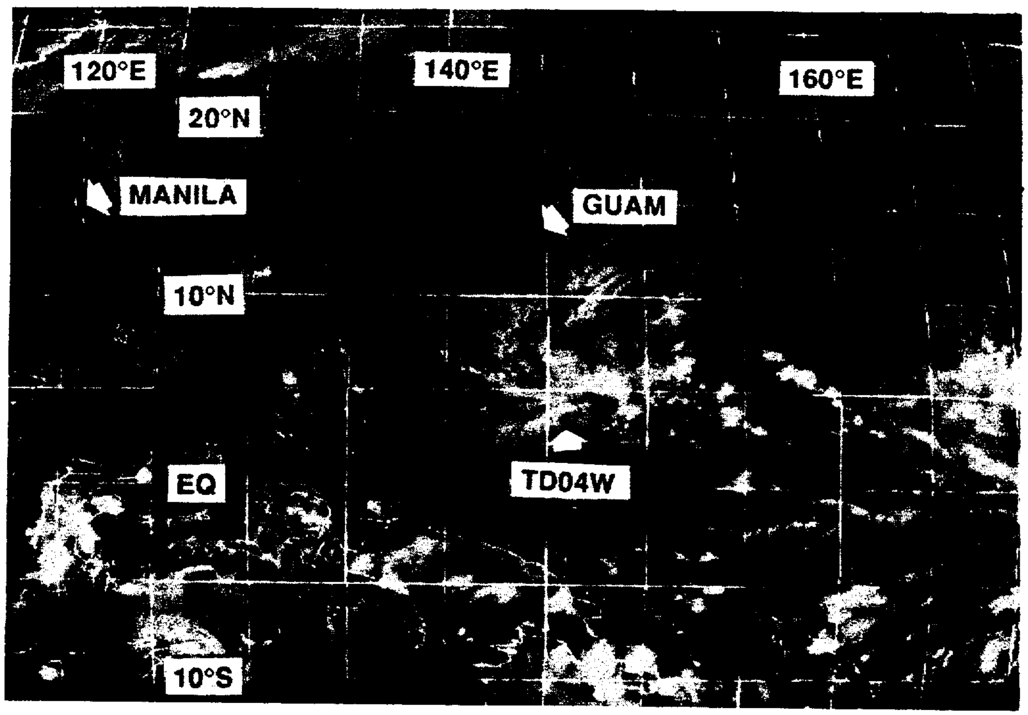
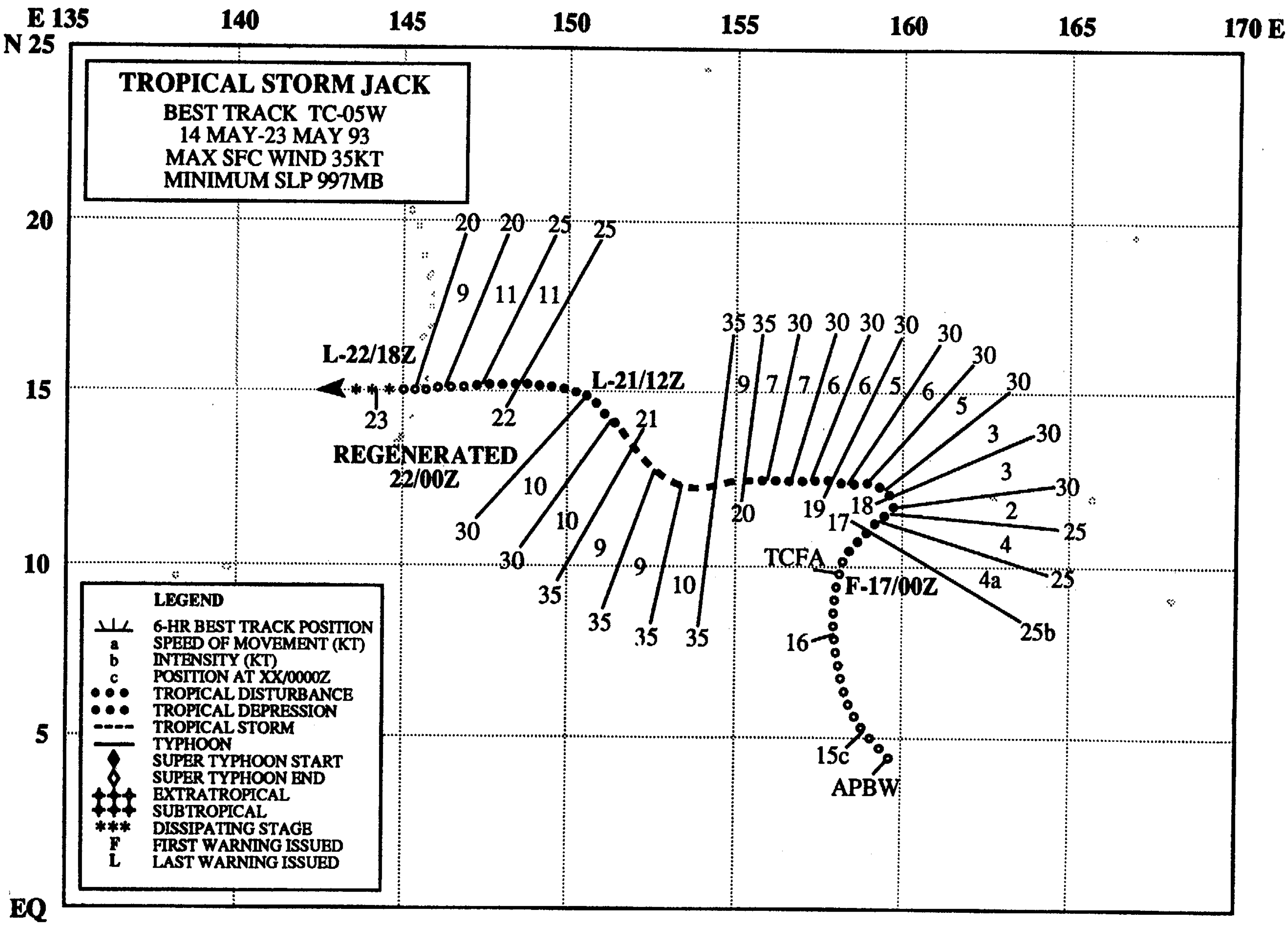


Figure 3-04-1 TD 04W passes to the south of Guam (221130Z April infrared GMS imagery).


TROPICAL STORM JACK
BEST TRACK TC-05W
14 MAY-23 MAY 93
MAX SFC WIND 35KT
MINIMUM SLP 997MB
E 135
140
145
150
155
160
165
170 E
N 25
20
15
10
5
EQ
L-22/18Z
L-21/12Z
REGENERATED
22/00Z
TCFA
F-17/00Z
APBW
15c
16
17
18
19
20
21
22
23
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM JACK (05W)

I. HIGHLIGHTS

The only significant tropical cyclone to occur during May, Tropical Storm Jack developed in association with an equatorial westerly wind burst (Luther et al., 1983), that involved Tropical Cyclone 27P (Adel) in the Solomon Islands in the Southern Hemisphere. As the maximum cloudiness associated with the westerly burst decreased, Jack moved steadily northward until 18 May when it turned to the west. Four days later, the tropical cyclone dissipated west of Saipan.

II. CHRONOLOGY OF EVENTS

May

140600Z - The tropical disturbance was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection to the south of Pohnpei in the eastern Caroline Islands.

161300Z - Tropical Cyclone Formation Alert was issued based on the appearance of a ragged central dense overcast.

170000Z - JTWC released the first warning on Tropical Depression 05W after analysis of the first daylight visual satellite imagery and receiving an intensity estimate of 25 kt (13 m/sec).

180600Z - Based on an satellite intensity estimate of 35 kt (18 m/sec), Jack was upgraded to a tropical storm. (Post analysis indicates Jack most probably became a tropical storm 42 hours later at 200000Z.)

211200Z - The loss of central convection led JTWC to issue a last warning on the circulation.

220000Z - Reintensification of Jack, as indicated by the appearance of persistent central convection, prompted JTWC to resume warnings (Figure 3-05-1).

221800Z - JTWC issued its final warning on Jack as the circulation dissipated just west of Saipan due to increased upper-level wind shear.

III. IMPACT

None.

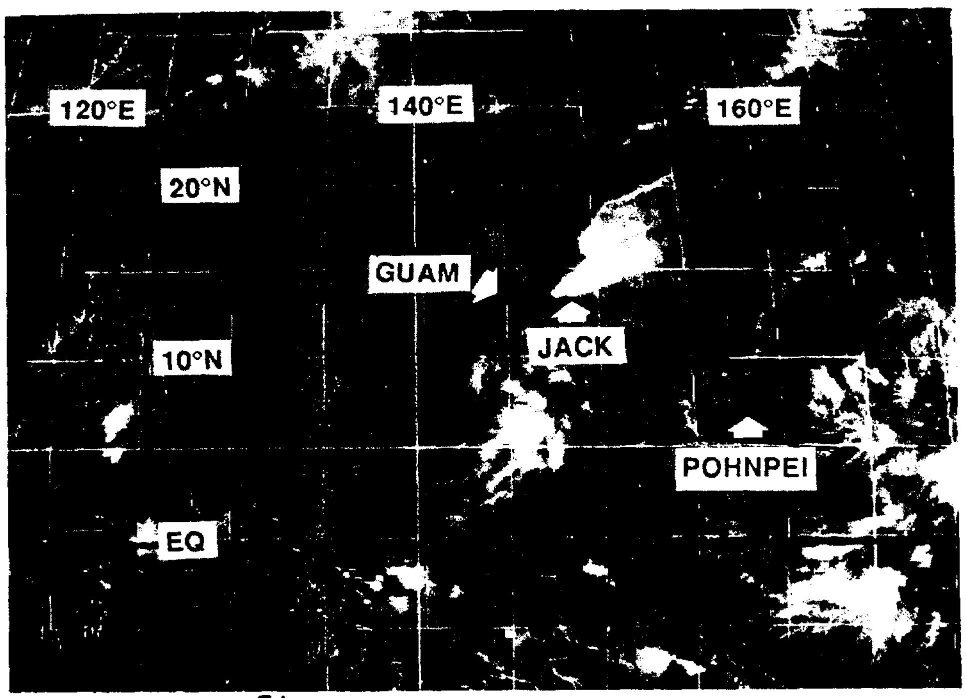
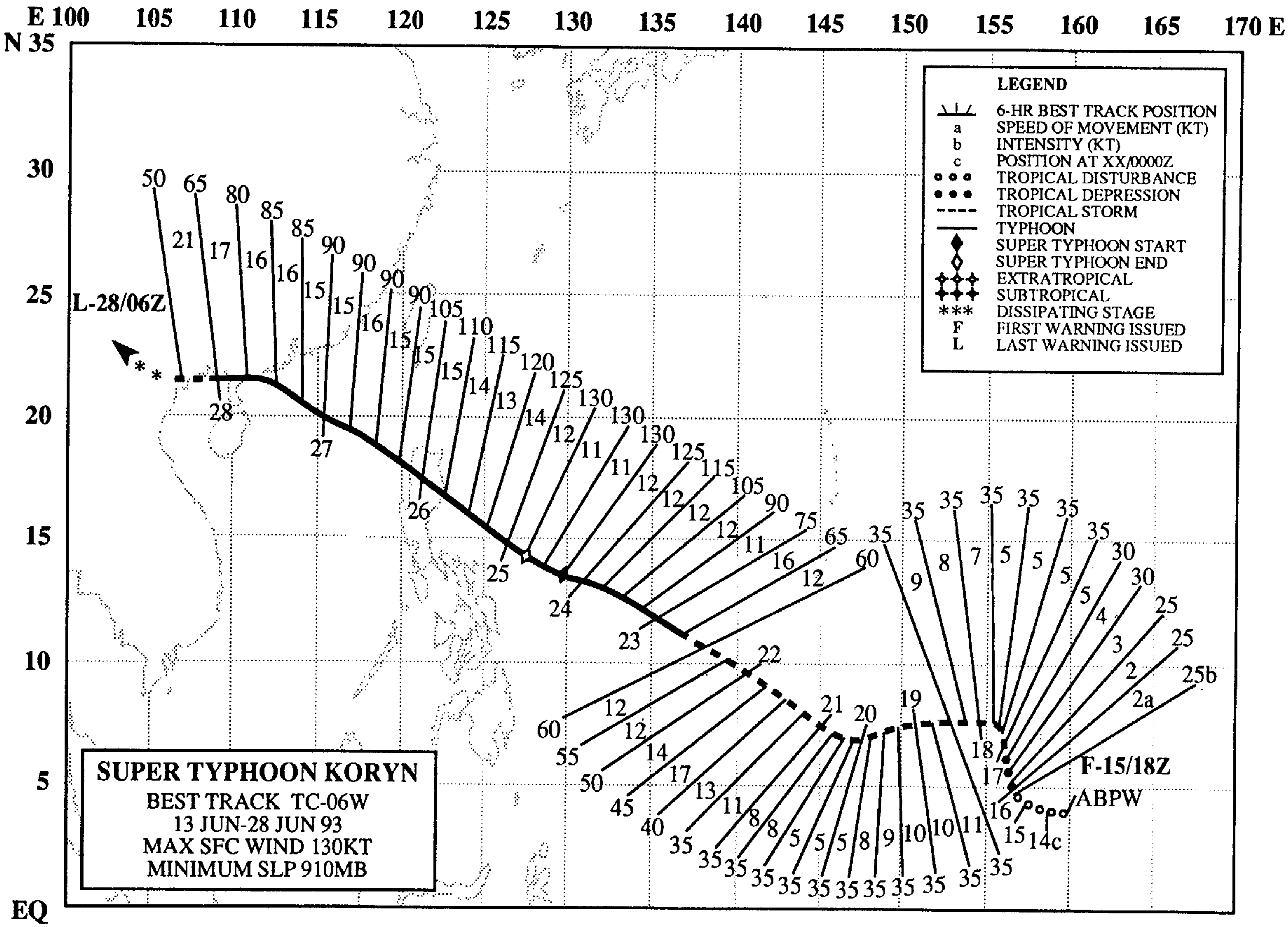


Figure 3-05-1 Jack's convection reappears just to the east of Guam (220132Z May infrared GMS imagery).


SUPER TYPHOON KORYN
BEST TRACK TC-06W
13 JUN-28 JUN 93
MAX SFC WIND 130KT
MINIMUM SLP 910MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-28/06Z
F-15/18Z
ABPW
E 100
105
110
115
120
125
130
135
140
145
150
155
160
165
170 E
N 35
30
25
20
15
10
5
EQ

SUPER TYPHOON KORYN (06W)

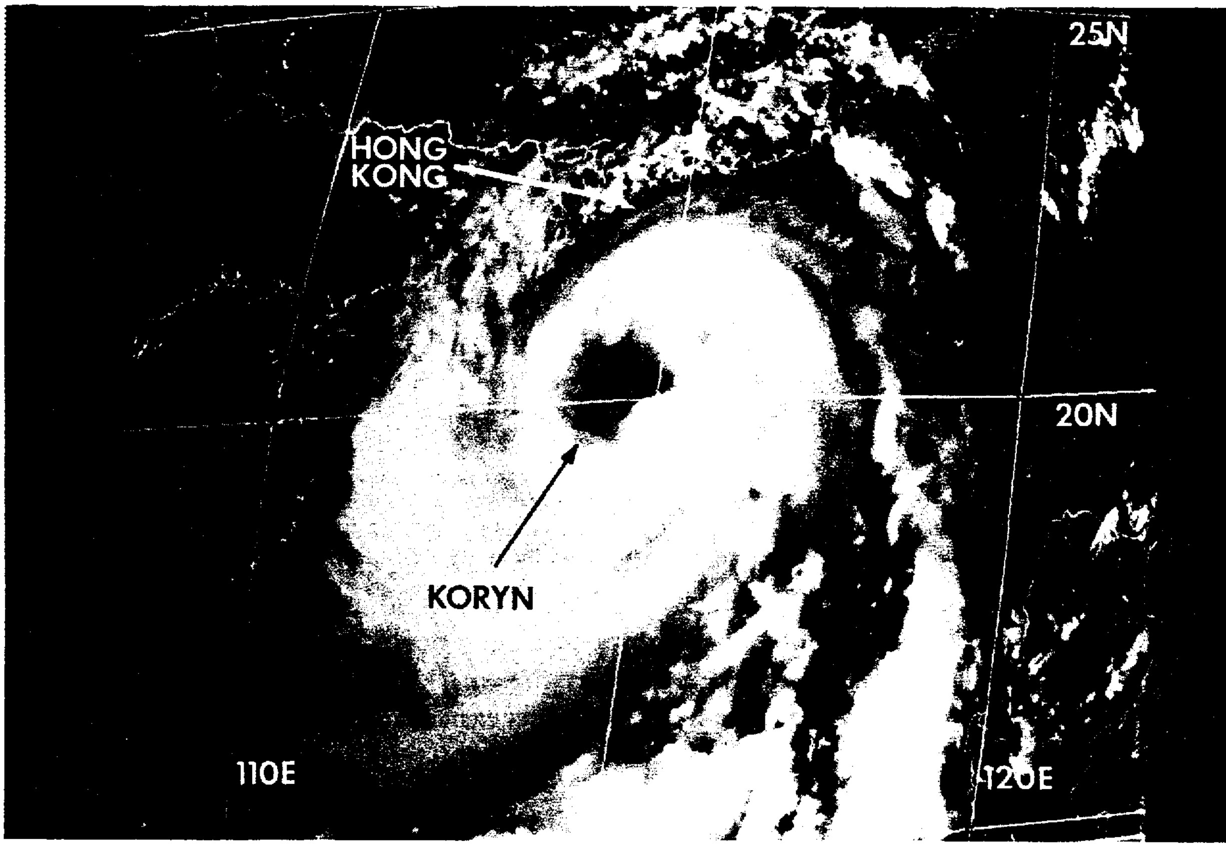


Figure 3-06-1 Koryn exhibits a large, ragged, cloud-free eye as it passes south of Hong Kong (262333Z June visual NOAA imagery).

I. HIGHLIGHTS

The first typhoon of the 1993 in western North Pacific, Koryn intensified slowly, taking over a week to attain minimal typhoon force winds. However, in 24 hours after its winds reached 65 kt (33 m/sec), the tropical cyclone rapidly doubled its intensity to become a super typhoon. After striking northern Luzon, Koryn entered the South China Sea and passed 90 nm (165 km) to the southeast of Hong Kong. Hong Kong experienced wind gusts to 92 kt (47 m/sec) and torrential rains (Figure 3-06-1).

II. CHRONOLOGY OF EVENTS

June

131800Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection located in the near equatorial trough in the eastern Caroline Islands.

151800Z - The first warning was issued based on a 25 kt (13 m/sec) northwesterly wind at Nukuoro Atoll (WMO 91425) and a satellite intensity estimate of 25 kt (13 m/sec).

170000Z - Based on a satellite intensity estimate of 35 kt (18 m/sec), Koryn was upgraded to a tropical storm.

230000Z - The appearance of a small 10 nm (19 km) diameter eye and the resulting satellite intensity estimate of 65 kt (33 m/sec) prompted an upgrade of Koryn to a typhoon.

240600Z - Based on a satellite Dvorak intensity estimate of 127 kt (65 m/sec), Koryn was upgraded to a super typhoon.

280600Z - The final warning was issued on Koryn as it rapidly dissipated over the mountains of northern Vietnam.

III. IMPACT

The passage of Koryn over Ulithi (WMO 91203) gave the island 5.53 in (140 mm) of rain and 60 kt (31 m/sec) winds. While there were no deaths or injuries reported, there was extensive damage to crops and vegetation as well as some roof damage to structures. In the Philippines on the island of Luzon, floods and landslides caused by Koryn's torrential rains left at least 28 people dead. Damage to crops, infrastructure, homes, and livestock was estimated to be over (US)$14.5 million.

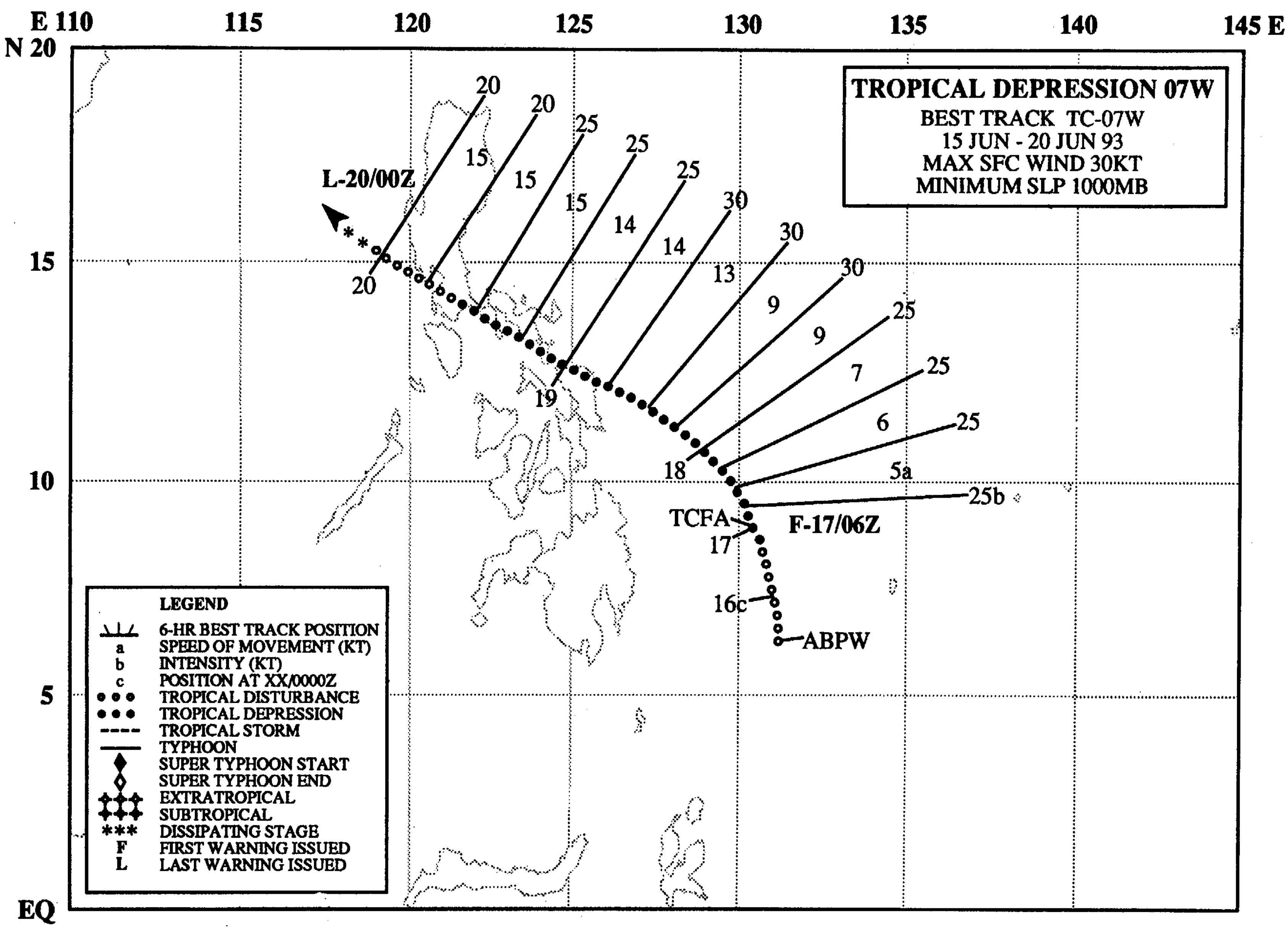
In Hong Kong, at least 183 people were injured, and a freighter, the 12,522-ton Lian Gang, sank 65 nm (120 km) southeast of Hong Kong with the loss of four of the crew. Koryn also lashed the coast of southern China's Guangdong Province, killing at least five people. No reports were received from Vietnam.

IV. DISCUSSION

The disturbance, that was to become Super Typhoon Koryn, first appeared at very low latitude (4°N) in the eastern Caroline Islands (near 160°E). From this birthplace, the disturbance moved northward, and then, upon attaining minimal tropical storm intensity, it made a 90-degree turn to the west. Initial northward motion, with a later turn to the west, has been observed with tropical cyclones that form at very low latitude in a near-equatorial trough, and, although a physical understanding of why or how the event takes place is little understood, the operational forecaster needs to anticipate its occurrence.

In the process of becoming a super typhoon, Koryn went through a period of rapid intensification for a period of 36 hours (221800Z to 240600Z). The 66-mb fall of the central pressure over these 36 hours represents an average pressure fall of 1.83 mb/hr which exceeds the 1.75 mb per hour criteria established for rapid intensification by Holliday and Thompson (1979).

While crossing northern Luzon, Koryn's weakened 20 kt (10 m/sec) — from 110 kt (57 m/sec) to 90 kt (46 m/sec) — which is well below the expected 45 kt (23 m/sec) as discussed in Shoemaker (1991) and Williams et al (1993) (S&W). This may be due to Koryn's rapid forward motion of 15 kt (28 km/hr): the faster the forward motion the less the weakening — a factor found by S&W.



TROPICAL DEPRESSION 07W
BEST TRACK TC-07W
15 JUN - 20 JUN 93
MAX SFC WIND 30KT
MINIMUM SLP 1000MB
E 110
115
120
125
130
135
140
145 E
N 20
15
10
5
EQ
L-20/00Z
F-17/06Z
TCFA
ABPW
16c
17
18
19
20
5a
25b
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL DEPRESSION 07W

I. HIGHLIGHTS

The final significant tropical cyclone of June, Tropical Depression 07W, was a short-lived system which formed in the monsoon trough east of Mindanao. After initially tracking northward, Tropical Depression 07W turned northwestward, crossed the central Philippines and dissipated (Figure 3-07-1).

II. CHRONOLOGY OF EVENTS

June

150600Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection within the monsoon trough.

170131Z - A Tropical Cyclone Formation Alert was issued following a consolidation of convection near the circulation center and a 20 kt (10 m/sec) ship report from the 161200Z surface streamline analysis.

170600Z - The first warning was issued based upon satellite intensity estimate of 25 kt (13 m/sec).

200000Z - The significant weakening of TD07W as it crossed the Philippine Islands prompted JTWC to cease warning on the system.

III. IMPACT

No reports received.

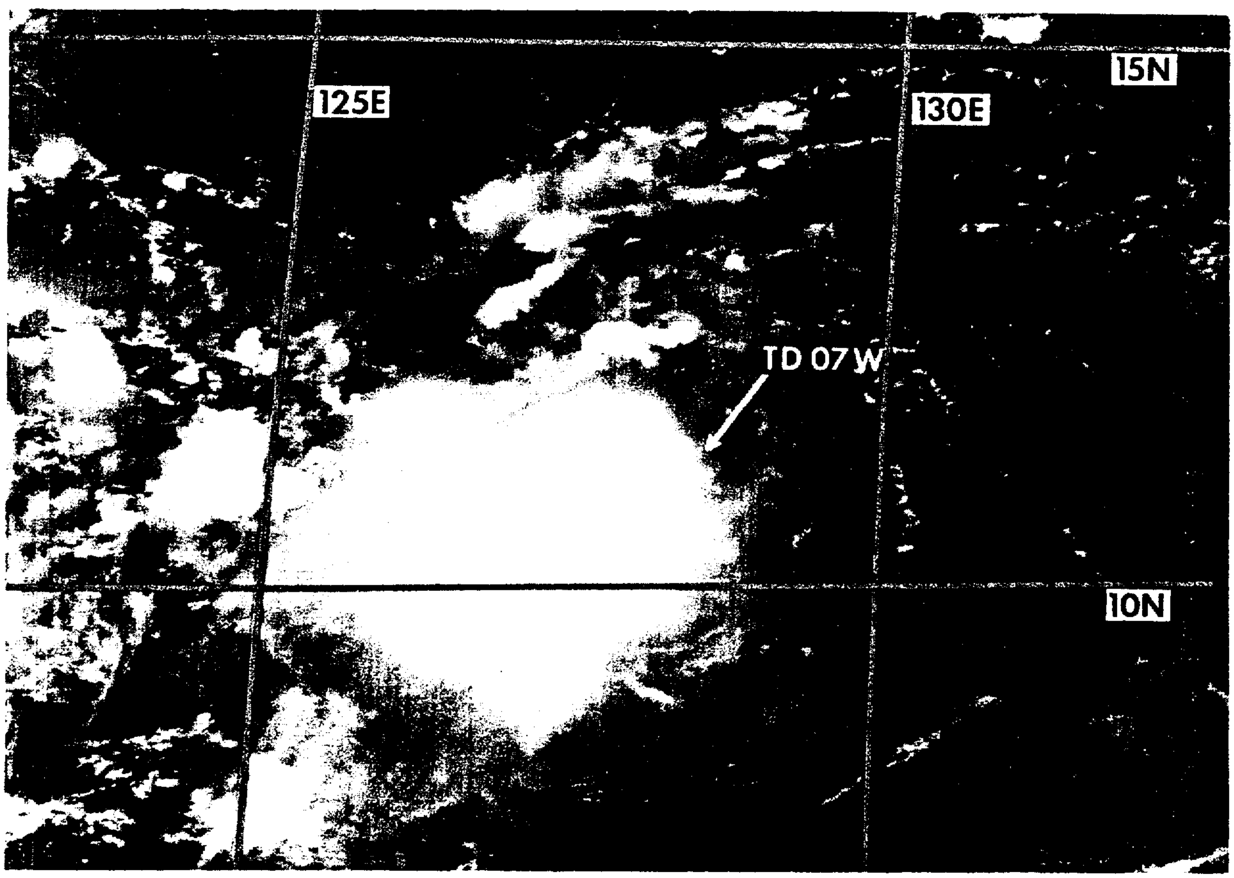
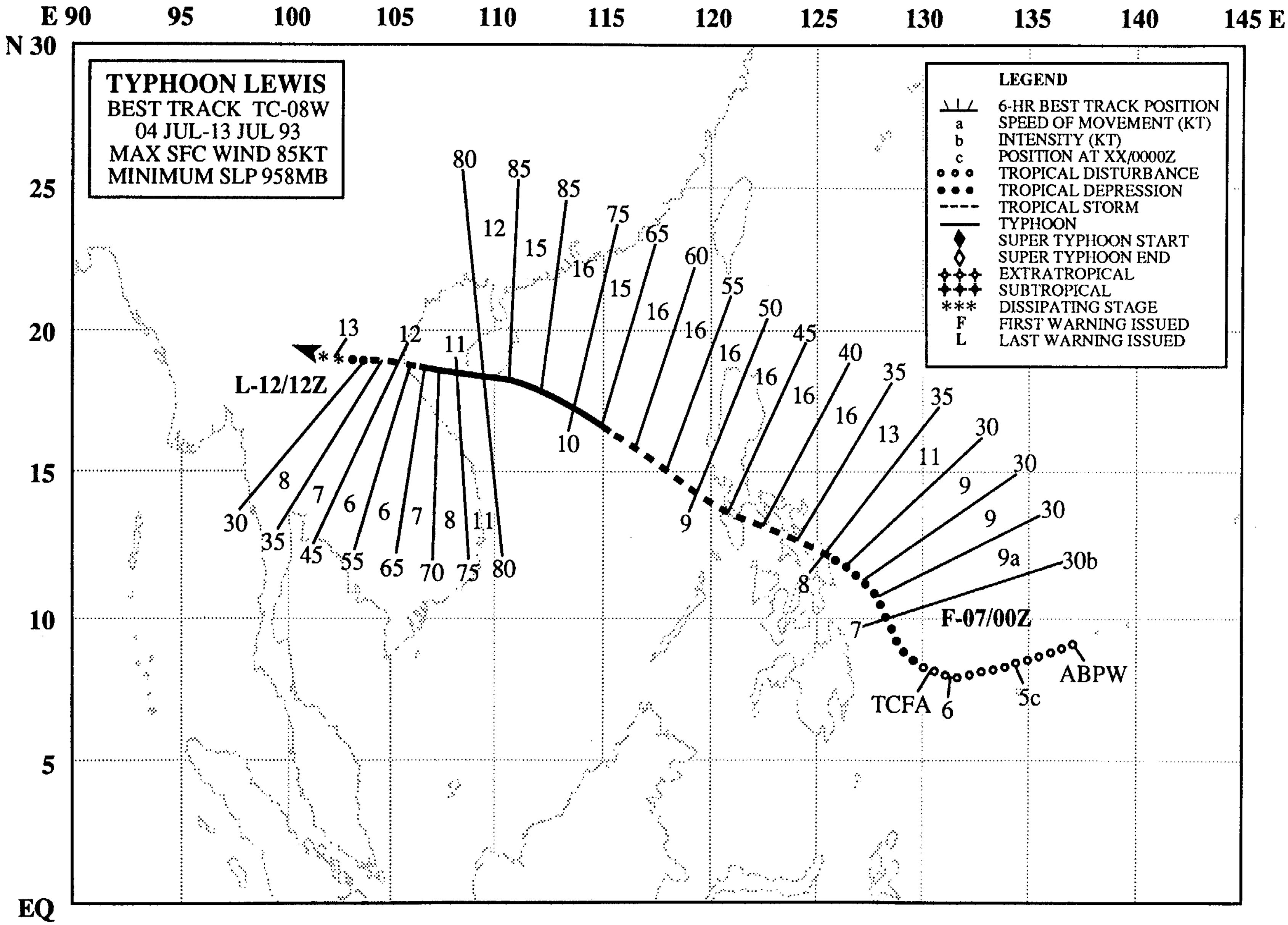


Figure 3-07-1 Approaching the central Philippines, TD 07W attains its peak intensity of 30 kt (15 m/sec)(180530Z June visual GMS imagery).


TYPHOON LEWIS
BEST TRACK TC-08W
04 JUL-13 JUL 93
MAX SFC WIND 85KT
MINIMUM SLP 958MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 90
95
100
105
110
115
120
125
130
135
140
145 E
N 30
25
20
15
10
5
EQ
L-12/12Z
F-07/00Z
TCFA
ABPW
9a
30b
5c

TYPHOON LEWIS (08W)

I. HIGHLIGHTS

Forming in the Philippine Sea, Typhoon Lewis was the first in a series of five significant tropical cyclones to occur during July. As it tracked west-northwestward, Lewis made landfall three times, over the central Philippines, Hainan Dao, and Vietnam, before dissipating over Thailand.

II. CHRONOLOGY OF EVENTS

July

040600Z - Persistent convection within the monsoon trough, east of the Philippine Islands, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

060630Z - A Tropical Cyclone Formation Alert was issued when satellite image animation revealed an increase in the amount and curvature of the convection.

070000Z - The first warning on Lewis was issued based upon the first daylight satellite image with an intensity estimate of 25 kt (13 m/sec).

081200Z - Following a synoptic report of 998.9 mb near the circulation center and supported by satellite intensity estimates, Lewis was upgraded to a tropical storm. Post analysis indicates Lewis most probably attained tropical storm intensity 12 hours earlier at 080000Z.

100000Z - Satellite intensity estimates of 65 kt (33 m/sec) resulted in Lewis being upgraded to a typhoon (Figure 3-08-1).

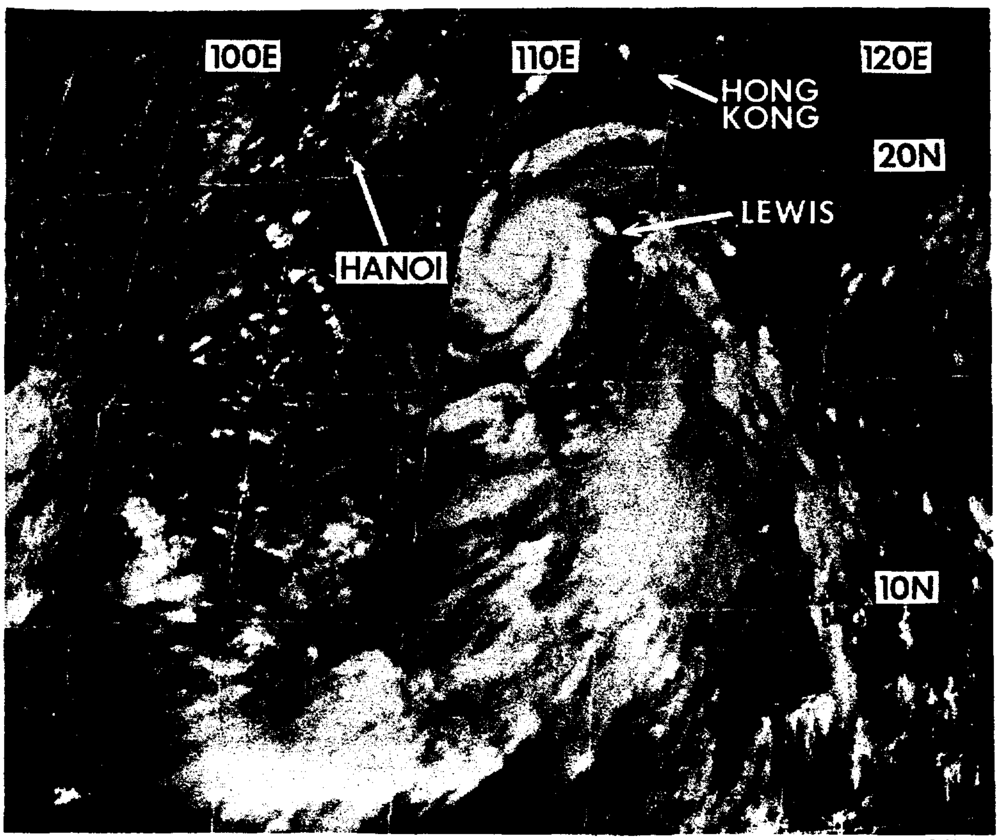
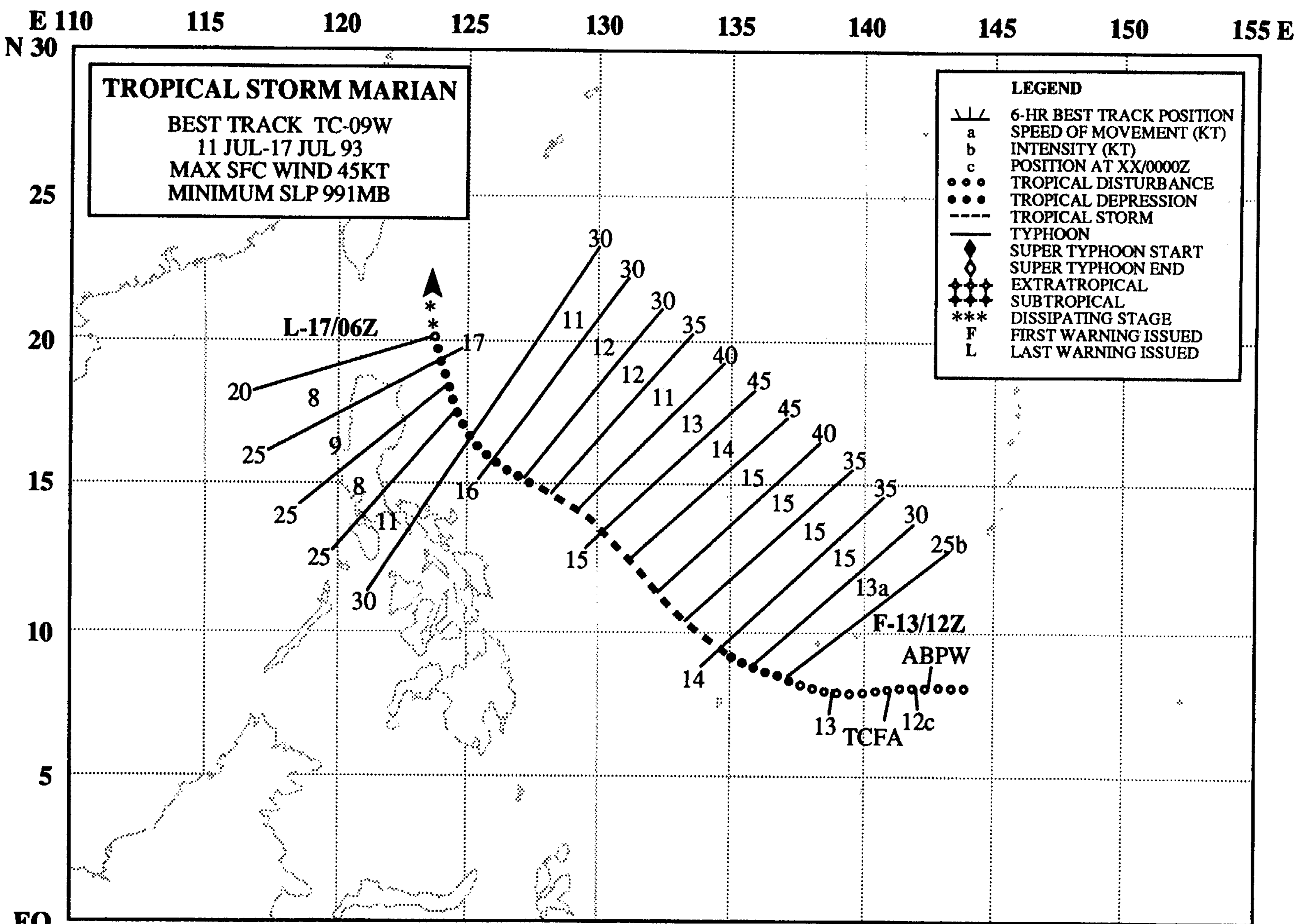


Figure 3-08-1 Tight coils of convection define Lewis shortly before the typhoon makes landfall on Hainan Dao (100530Z July visual GMS imagery).

121200Z - The final warning on Lewis was issued as the tropical cyclone rapidly weakened over the mountains of Southeast Asia.

III. IMPACT

News releases from Vietnam attributed two deaths, two injuries, and eight people missing to Lewis' passage. In northeast Thailand, flash floods damaged farmlands and more than 100 roads and bridges as the remnants of Lewis tracked westward.


TROPICAL STORM MARIAN
BEST TRACK TC-09W
11 JUL-17 JUL 93
MAX SFC WIND 45KT
MINIMUM SLP 991MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 110
115
120
125
130
135
140
145
150
155 E
N 30
25
20
15
10
5
EQ
L-17/06Z
F-13/12Z
ABPW
TCFA
25b
13a
12c

TROPICAL STORM MARIAN (09W)

I. HIGHLIGHTS

Forming within the monsoon trough, Marian tracked northwestward towards northern Luzon, then took a more northward track before dissipating in the Philippine Sea. Strong, persistent upper-level winds inhibited development and ultimately led to Tropical Storm Marian's dissipation.

II. CHRONOLOGY OF EVENTS

July

111900Z - A persistent convection embedded in the monsoon trough in the western Caroline Islands was first mentioned in the Significant Tropical Weather Advisory

120800Z - A Tropical Cyclone Formation Alert (TCFA) was issued following an increase in convective organization (Figure 3-09-1). Because the tropical disturbance was slow to develop, the TCFA with reissued 24 hours later.

131200Z - Rapidly improving convective organization resulted in a satellite intensity estimate of 25 kt (13 m/sec) which prompted JTWC to issue the first warning.

140000Z - Based upon a satellite intensity estimate of 35 kt (18 m/sec), Marian was upgraded to tropical

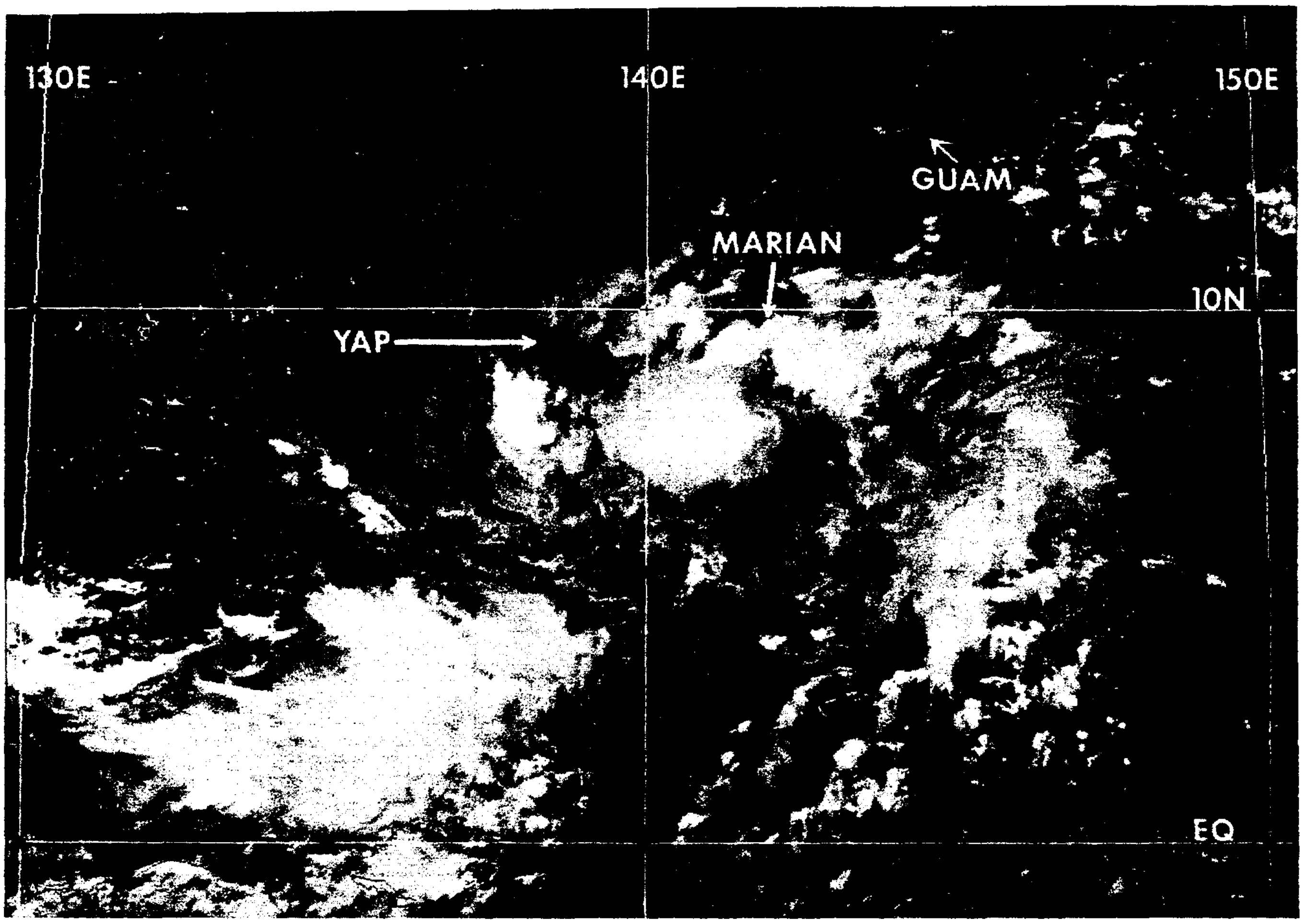
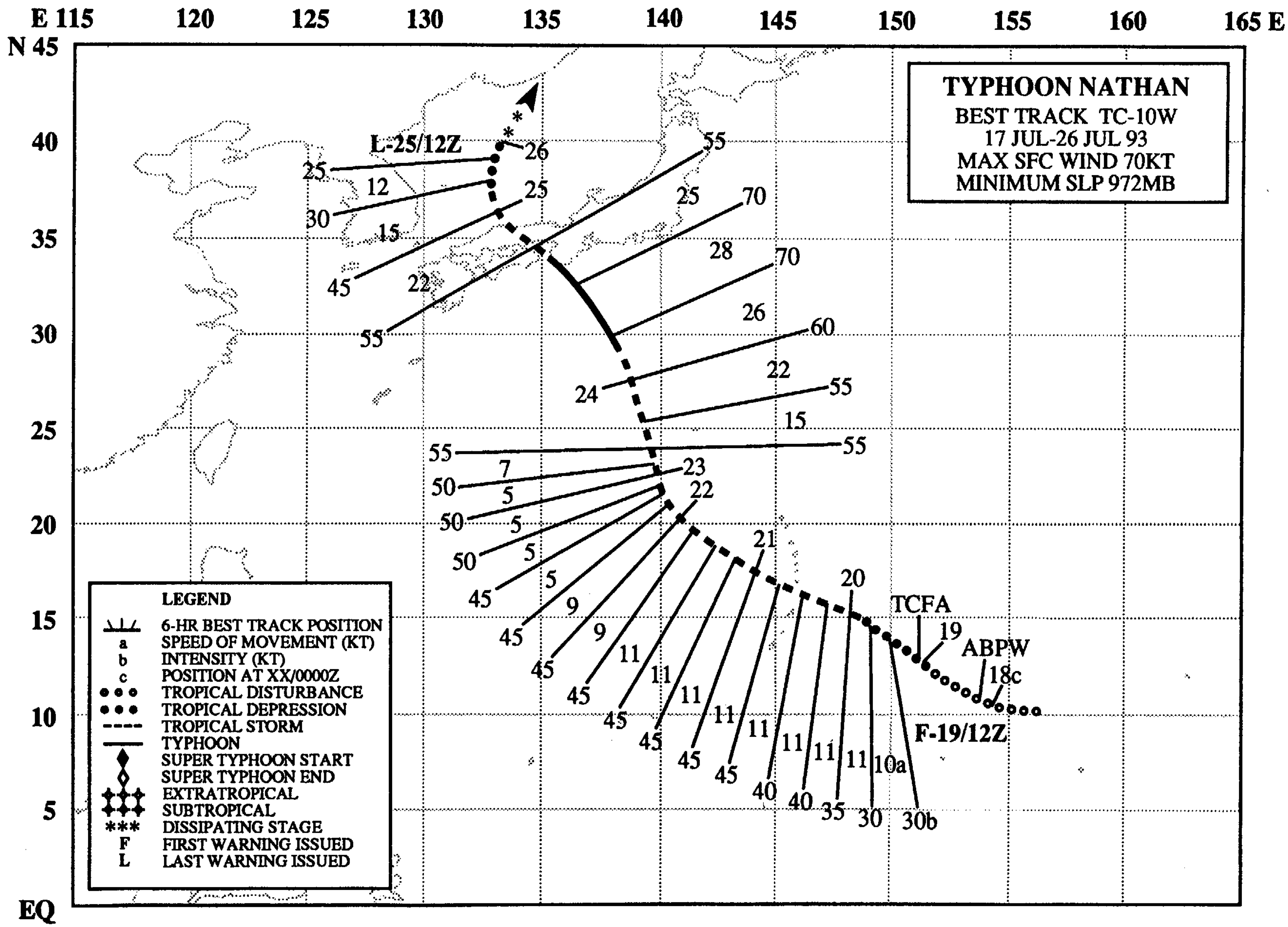


Figure 3-09-1 Marian, which is slowly intensifying, approaches the island of Yap (120425Z July visual GMS imagery).


TYPHOON NATHAN
BEST TRACK TC-10W
17 JUL-26 JUL 93
MAX SFC WIND 70KT
MINIMUM SLP 972MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-25/12Z
F-19/12Z
TCFA
ABPW
E 115
120
125
130
135
140
145
150
155
160
165 E
N 45
40
35
30
25
20
15
10
5
EQ

TYPHOON NATHAN (10W)

I. HIGHLIGHTS

After passing through the central Mariana Islands, Nathan interacted with a monsoon gyre which had formed in the Philippine Sea. Approaching the SW-NE oriented cloud band associated with the monsoon gyre, Nathan turned to the north to occupy a position at the northeastern end of that cloud band. From this position, Nathan accelerated rapidly (northward at first, then tending more northwesterly); and, breaking free of the monsoon cloud band, raced across southwestern Japan. Later, it entered the Sea of Japan, where it slowed in forward speed and dissipated. Operationally, Nathan was most notable for it's impact on Exercise Tandem Thrust in the Mariana Islands and it's rapid acceleration towards Japan. JTWC forecasts were hampered by the inability of the NOGAPS model to simultaneously handle a cutoff low south of Kyushu as Nathan rapidly approached Japan.

II. CHRONOLOGY OF EVENTS

July

170600Z - An area of persistent convection within the monsoon trough, northwest of Pohnpei, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

190200Z - An increase in both the amount and curvature of the convection east of the Mariana Islands, led to issuance of a Tropical Cyclone Formation Alert.

191200Z - Consolidation of central cloudiness and the resulting satellite intensity estimate of 25 kt (13 m/sec) prompted the first warning. Post analysis of satellite and synoptic data indicated that the formation of the tropical depression most probably occurred 12 hours earlier at 190000Z.

200000Z - Based upon a satellite intensity estimate of 35 kt (18 m/sec), Nathan was upgraded to a tropical storm.

240600Z - The appearance of a ragged, cloud-filled eye and a satellite intensity estimate of 77 kt (40 m/sec) led to Nathan's upgrade to a typhoon.

251200Z - The final warning was issued on Nathan as it dissipated in the Sea of Japan.

III. IMPACT

The approach of Tropical Storm Nathan towards Saipan and Tinian in the central Mariana Islands hindered operations during Exercise Tandem Thrust.

IV. DISCUSSION

During the latter half of July 1993, the monsoon circulation of the western North Pacific became organized as a monsoon gyre (see definition in Appendix A and Figure 3-10-1). The monsoon gyre of July 1993 was associated with the formation of two and the motion of three very small tropical cyclones: Nathan, Ofelia (11W), and Percy (12W). Fortuitously, the Office of Naval Research and the Naval Postgraduate School were conducting a mini-field experiment, Tropical Cyclone Motion 1993 (TCM-93) (see Harr et al., 1993 for details), during the lifetime of this monsoon gyre. In support of TCM-93, an Air Force Reserve WC-130 weather reconnaissance aircraft from the 815th Weather Squadron was deployed to Guam to obtain measurements in and around tropical cyclones in the western North Pacific.

By 21 July, an independent large-scale cyclonic vortex had formed in the tropics of the western North Pacific. This vortex and its accompanying low-pressure area moved westward over the next 10 days, and influenced the motion of Nathan, Ofelia (11W), and Percy (12W). In each case, the tropical cyclone emerged from the downstream head of the monsoon cloud band, escaped from the gyre circulation and followed a "north-oriented" track (JMA, 1976) over Japan. Noted by Harr et al. (1993), each storm formed westward of the previous storm as the monsoon gyre drifted westward (Figure 3-10-2). By the first of August 1993, the monsoon gyre had merged with the low-pressure area over the Asian land mass.

During the westward migration of the July 1993 monsoon gyre, a successful forecast of sequential tropical cyclone development (each predicted to form to the west of the one prior) in the northeastern quadrant of the monsoon gyre was made by the TCM-93 forecast team in conjunction with JTWC forecasters. Three aircraft missions were flown during the period of genesis and intensification of the second gyre-related tropical cyclone, Ofelia (see Harr et al., 1993). The TCM-93 data set may provide a means to examine the mechanisms leading to the formation of midget or very small tropical cyclones in the peripheral cloud band of a monsoon gyre.

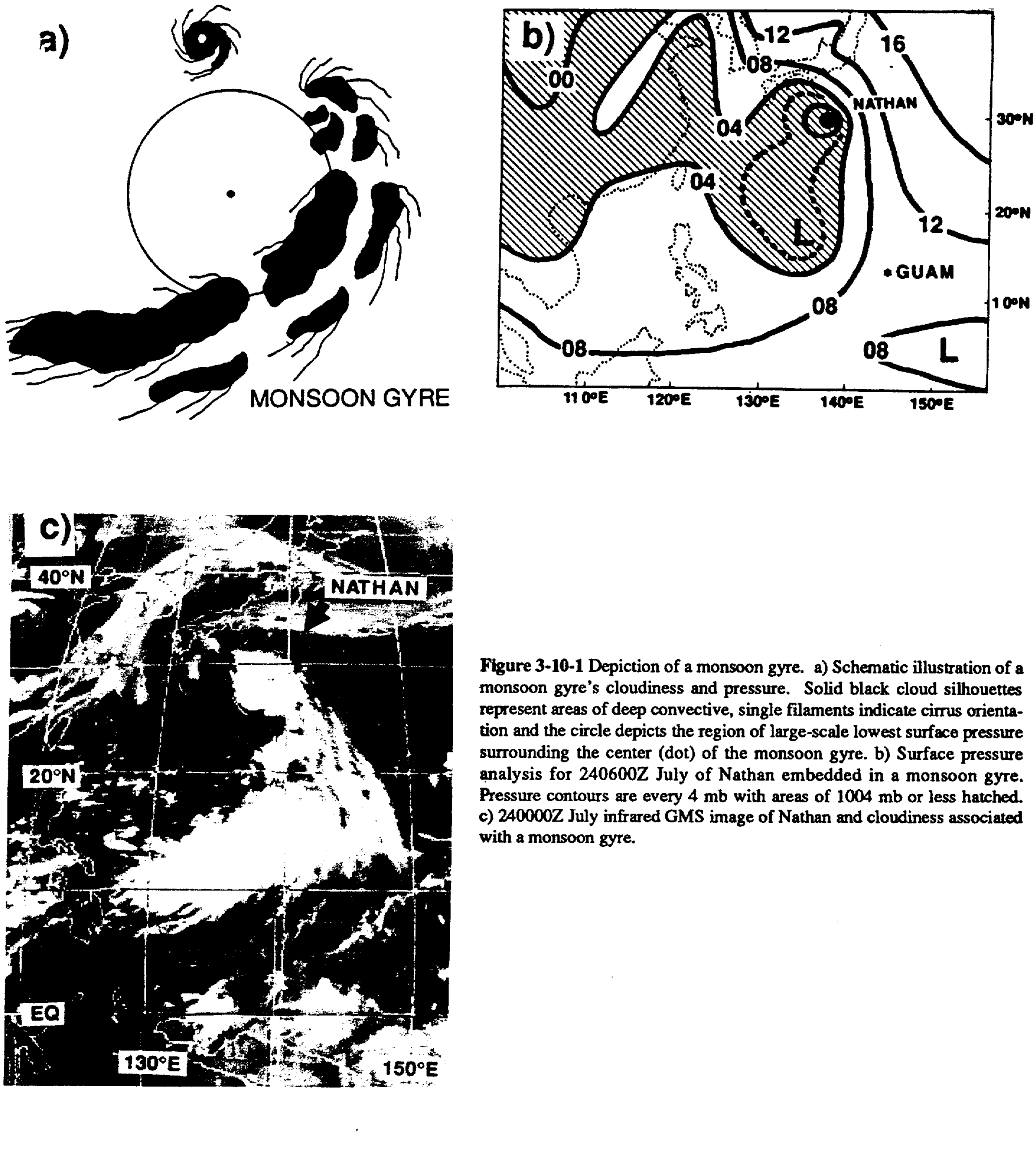


Figure 3-10-1 Depiction of a monsoon gyre. a) Schematic illustration of a monsoon gyre's cloudiness and pressure. Solid black cloud silhouettes represent areas of deep convective, single filaments indicate cirrus orientation and the circle depicts the region of large-scale lowest surface pressure surrounding the center (dot) of the monsoon gyre. b) Surface pressure analysis for 240600Z July of Nathan embedded in a monsoon gyre. Pressure contours are every 4 mb with areas of 1004 mb or less hatched. c) 240000Z July infrared GMS image of Nathan and cloudiness associated with a monsoon gyre.

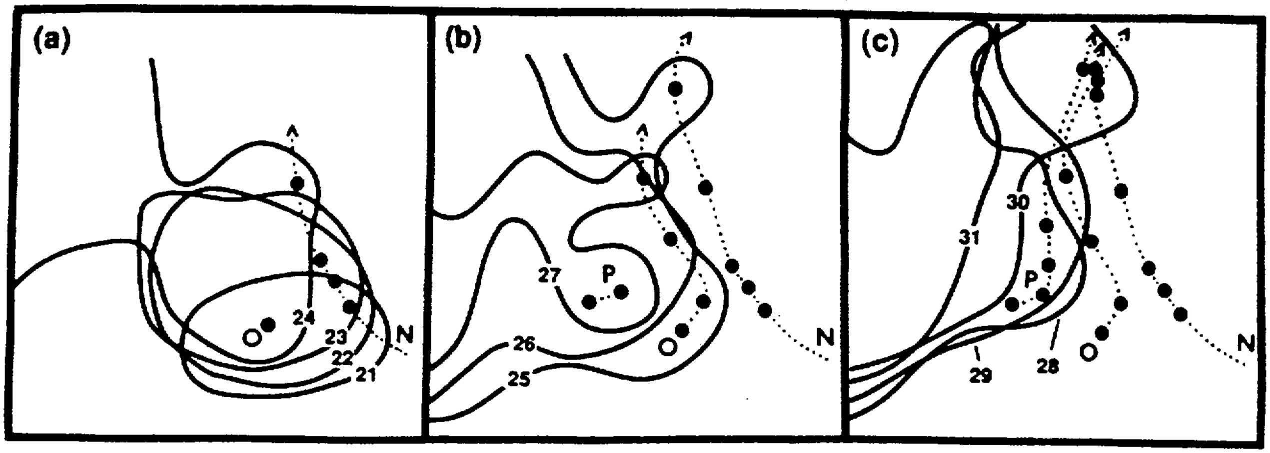
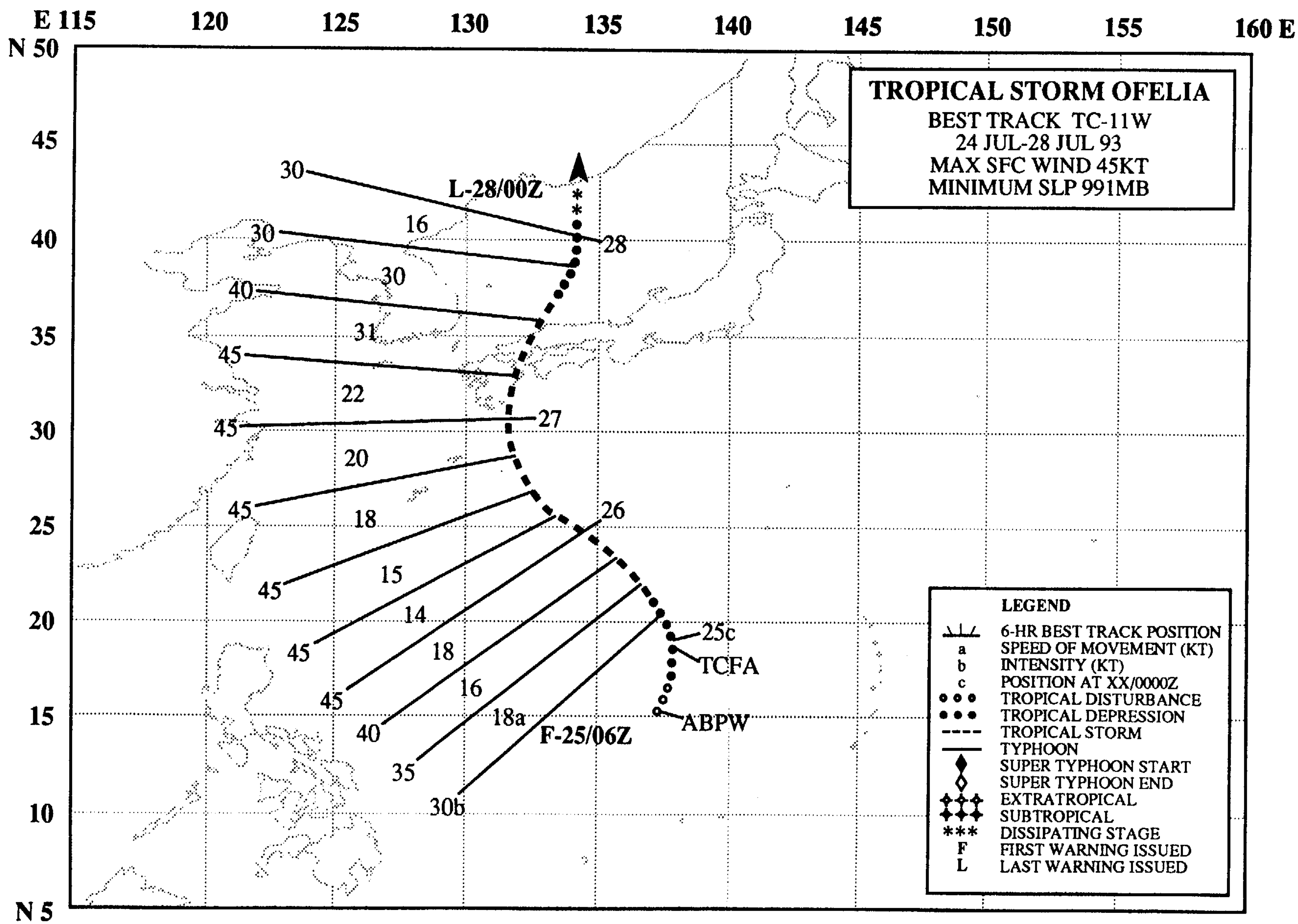


Figure 3-10-2 Illustration of the west-northwestward movement of the monsoon gyre of July 1993. a) The 1008, 1008, 1006 and 1004 mb contour of sea-level pressure (SLP) at 06Z July 21, 22, 23 and 24 respectively. b) The 1006 mb contour of SLP at 06Z July 25, 26 and 27. c) The 1006 mb contour of SLP at 067Z July 28, 29, 30 and 31. Dots show 06Z position of Nathan (N), Ofelia (O) and Percy (P) which show on each panel.


TROPICAL STORM OFELIA
BEST TRACK TC-11W
24 JUL-28 JUL 93
MAX SFC WIND 45KT
MINIMUM SLP 991MB
E 115
120
125
130
135
140
145
150
155
160 E
N 50
45
40
35
30
25
20
15
10
N 5
L-28/00Z
F-25/06Z
ABPW
TCFA
25c
26
27
28
30
16
30
30
40
31
45
22
45
20
45
18
45
15
45
14
45
18
40
16
35
18a
30b
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM OFELIA (11W)

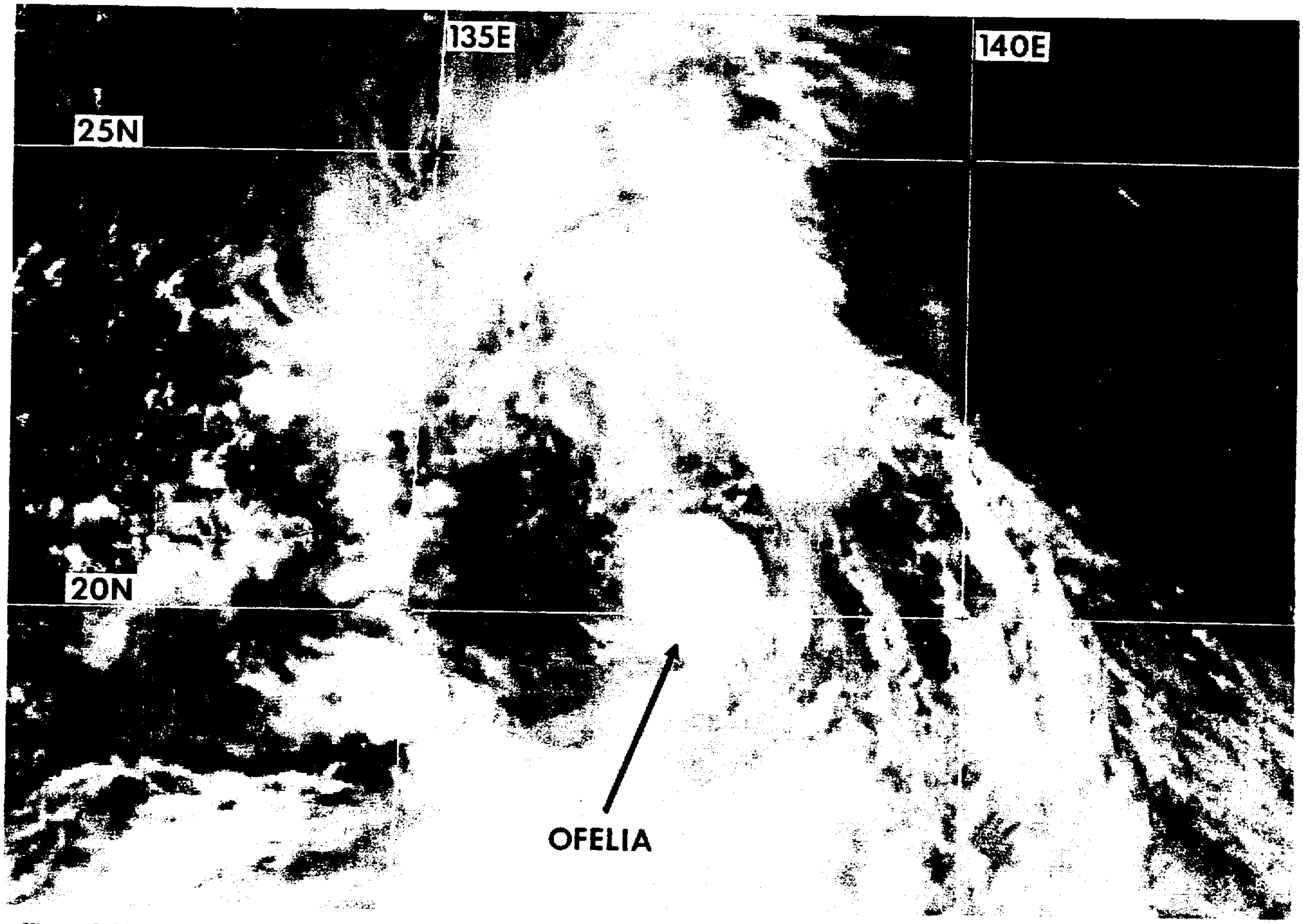


Figure 3-11-1 Ofelia with a rapidly developing CDO begins its separation from the monsoon cloud band (250531Z July visual GMS imagery).

I. HIGHLIGHTS

Forming in association with a monsoon gyre, Ofelia was the only system not to attain typhoon intensity during July. Ofelia was of interest due to its unusually rapid initial development and small size (Figure 3-11-1). Because of TCM-93, valuable additional data from Air Force aircraft weather reconnaissance describing this tropical cyclone were available to JTWC forecasters.

II. CHRONOLOGY OF EVENTS

July

240600Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection in the Philippine Sea.

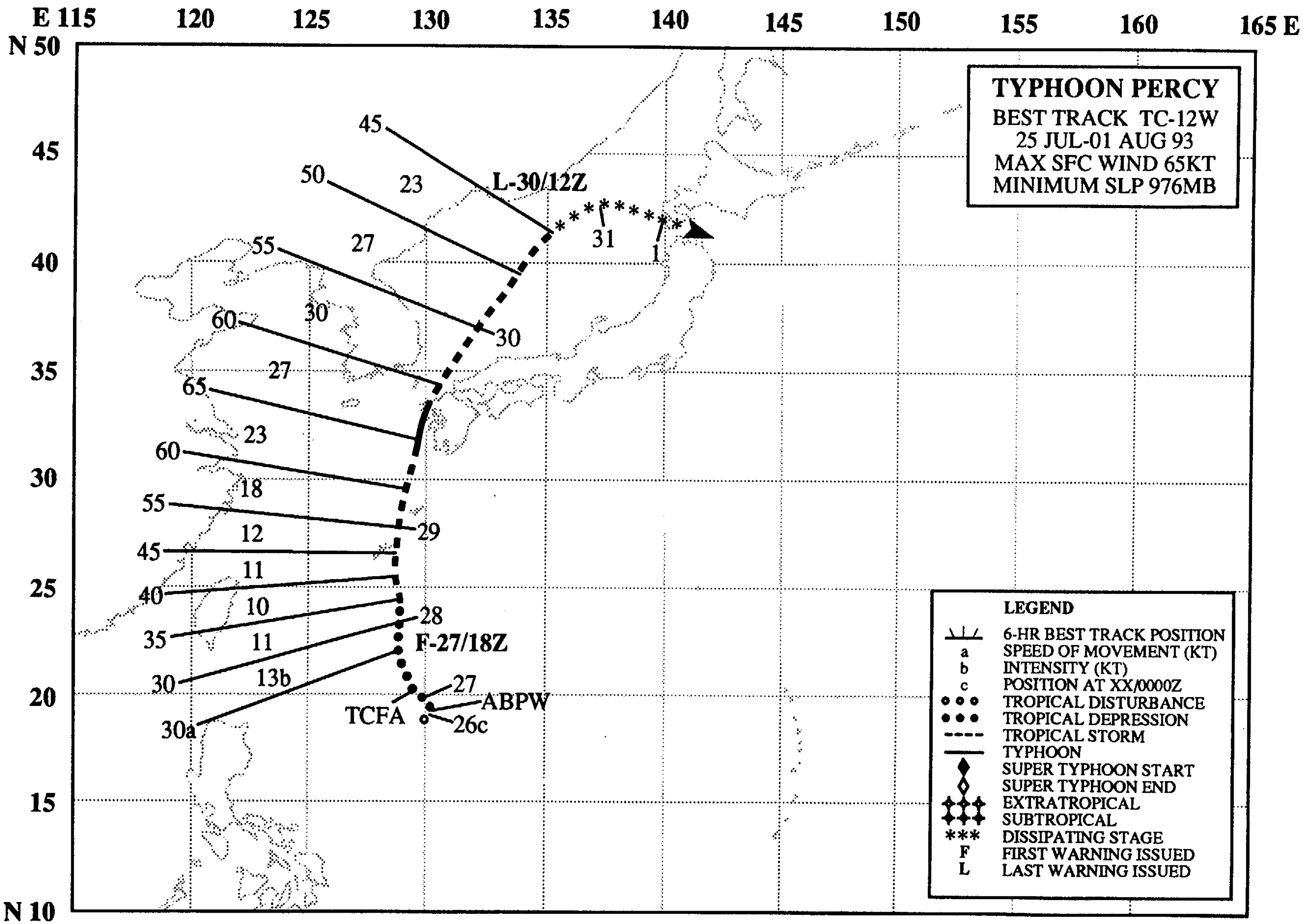
242200Z - A Tropical Cyclone Formation Alert was issued based upon the first daylight visual satellite image showing a well organized exposed low-level circulation center.

250600Z - Due to the unusually rapid growth of a central dense overcast (CDO) over the low-level circulation center, the first warning was issued for a tropical storm. Post analysis indicated that Ofelia most probably reached tropical storm intensity at 250900Z.

280000Z - The final warning was issued as Ofelia dissipated over the Sea of Japan.

III. IMPACT

No reports received.


TYPHOON PERCY
BEST TRACK TC-12W
25 JUL-01 AUG 93
MAX SFC WIND 65KT
MINIMUM SLP 976MB
E 115
120
125
130
135
140
145
150
155
160
165 E
N 50
45
40
35
30
25
20
15
N 10
L-30/12Z
F-27/18Z
TCFA
ABPW
26c
27
28
29
30
31
1
30a
13b
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON PERCY (12W)

I. HIGHLIGHTS

The final significant tropical cyclone to spin out of a monsoon gyre, Typhoon Percy, also followed a north-oriented track towards Japan. Forming in the Philippine Sea, Percy briefly attained typhoon intensity, but was most notable for it's rapid acceleration towards Japan after passing near Okinawa (Figure 3-12-1).

II. CHRONOLOGY OF EVENTS

July
260600Z - An area of persistent convection, which separated from a large area of deep convection associated with converging monsoonal flow into Tropical Storm Ofelia (11W), resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.
270600Z - A Tropical Cyclone Formation Alert was issued as monsoonal wind flow across the Philippine Sea enhanced convection associated with the disturbance.
271800Z - The first warning was issued based upon a consolidation of convection near the circulation center and a satellite intensity estimate of 25 kt (13 m/sec).
280600Z - Based upon a synoptic report, which indicated 25 kt (13 m/sec) southerly winds located 60 nm (111 km) from the circulation center, Percy was upgraded to a tropical storm.
291200Z - The appearance of a cloud filled eye and the resulting satellite intensity estimate of 65 kt (33 m/sec) prompted the upgrade to a typhoon.
301200Z - The final warning was issued on Percy as it dissipated in the Sea of Japan.

III. IMPACT

The highest reported wind gusts on Okinawa — 49 kt (25 m/sec) — occurred at Naha (WMO 47936). Later, Amami, Japan (WMO 47909), in the northern Ryukyu Islands, reported maximum wind gusts of 69 kt (36 m/sec). No reports of damage were received.

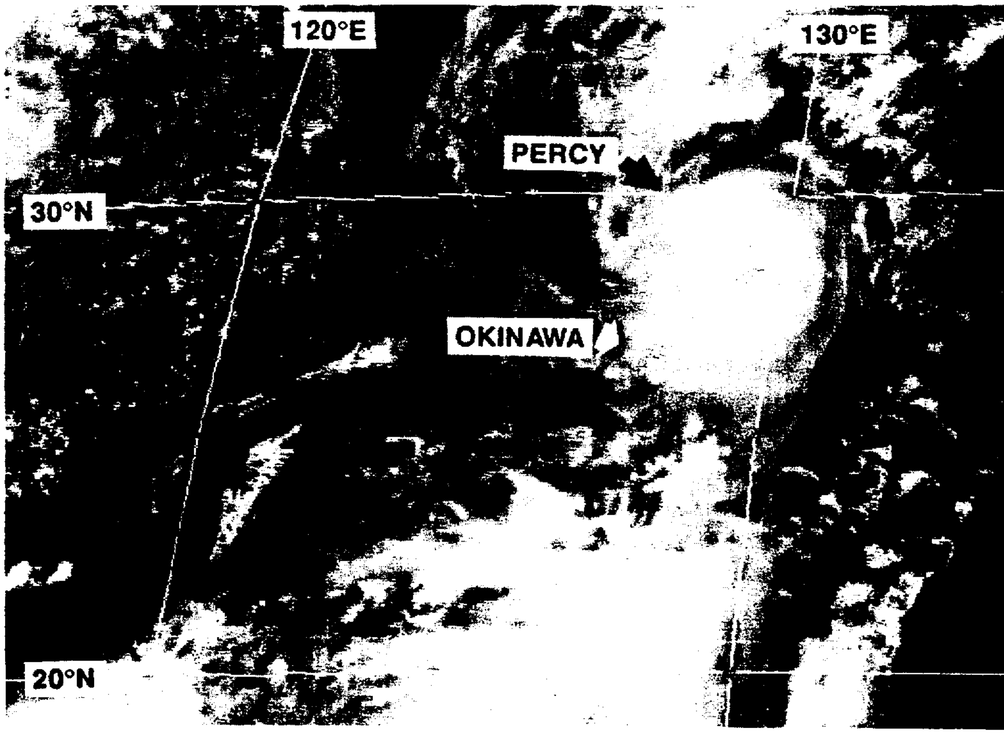
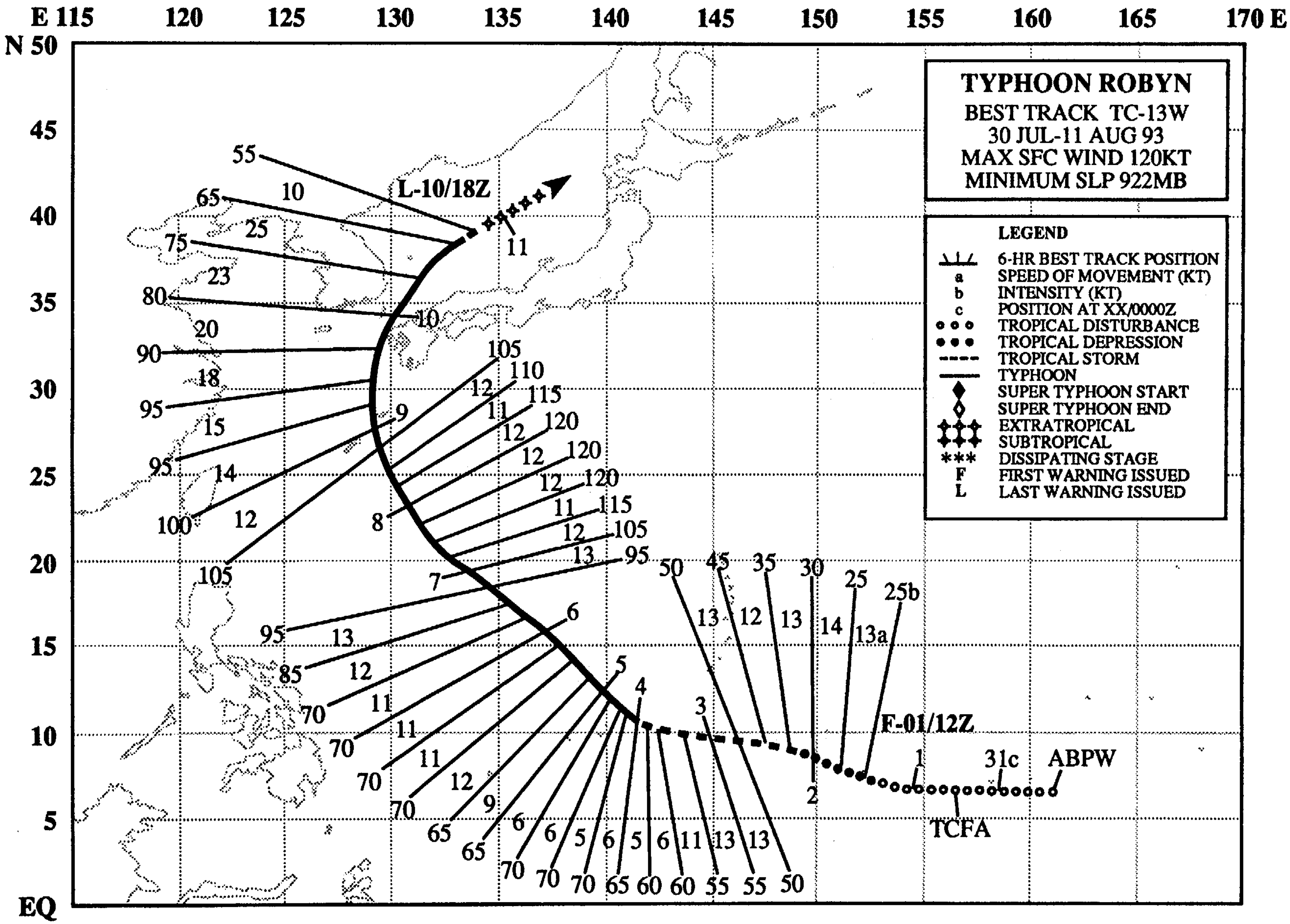


Figure 3-12-1 Percy brushes by Okinawa (290424Z July visual GMS imagery).


TYPHOON ROBYN
BEST TRACK TC-13W
30 JUL-11 AUG 93
MAX SFC WIND 120KT
MINIMUM SLP 922MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-10/18Z
F-01/12Z
TCFA
ABPW
E 115
120
125
130
135
140
145
150
155
160
165
170 E
N 50
45
40
35
30
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5
EQ

TYPHOON ROBYN (13W)

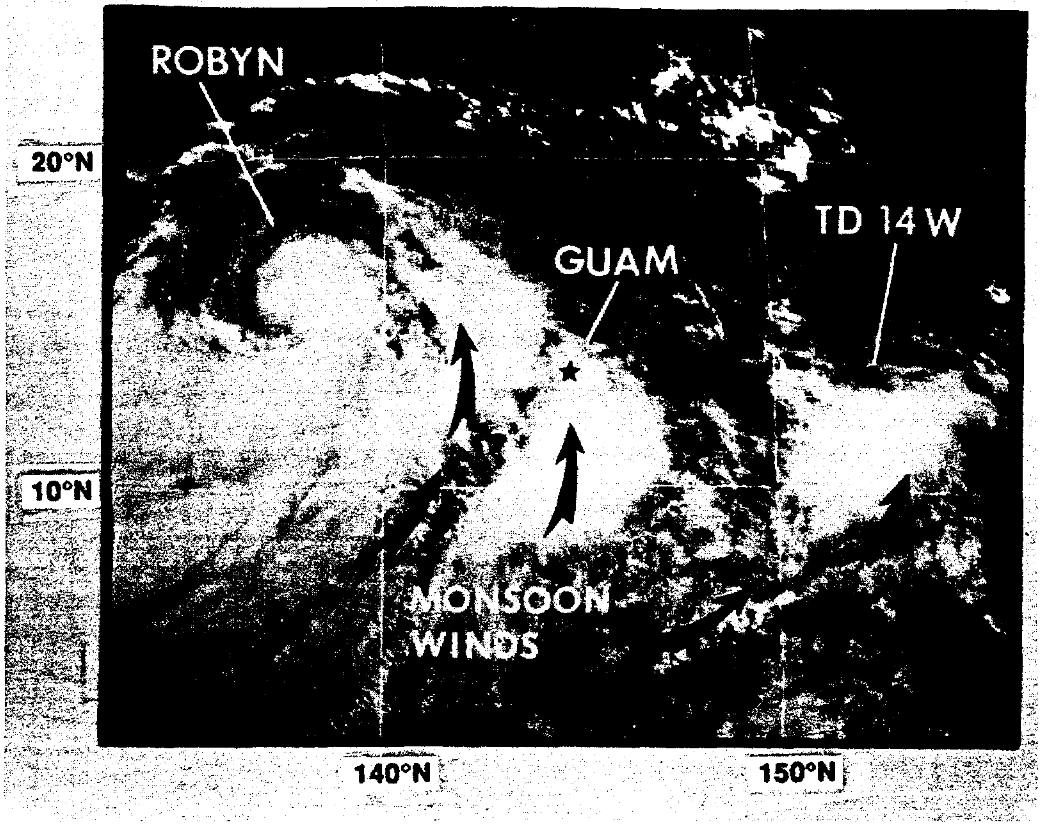


Figure 3-13-1 Typhoon Robyn with its associated rain and monsoon southwesterly winds churns northwestward towards Ryukyu Islands (052224Z August visual GMS Imagery).

I. HIGHLIGHTS

The sixth and final tropical cyclone of July, Robyn, formed in the near equatorial trough in the eastern Caroline Islands. This typhoon was notable for its large size, and for the fact that it was one of three to impact both Okinawa and Sasebo, Japan in 1993. Data from a WC-130 weather reconnaissance aircraft flying in support of TCM-93 were used to support tracking and forecasting.

II. CHRONOLOGY OF EVENTS

July

300600Z - An area of persistent convection in the near equatorial trough resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory..

311300Z - A Tropical Cyclone Formation Alert was issued based on indications from animated satellite imagery, synoptic reports and weather reconnaissance observations that a cyclonic circulation was developing.

August

011200Z - The first warning was issued based on a satellite intensity estimate of 25 kt (13 m/sec).

020600Z - Based on a satellite intensity estimate of 35 kt (18 m/sec), Robyn was upgraded to a tropical storm, about 250 nm (463 km) northwest of Chuuk.

030600Z - Based on a satellite intensity estimate of 65 kt (33 m/sec), Robyn was upgraded to a typhoon.

Post analysis of subsequent satellite and aircraft data indicated that the system most probably reached typhoon intensity at 040000Z.
080835Z - The JTWC transferred warning responsibility for Robyn to the AJTWC at Pearl Harbor, Hawaii after an 8.1 magnitude earthquake centered near Guam interrupted power and communications at JTWC.
082130Z - The JTWC resumed warning responsibility.
101800Z - The final warning was issued on Robyn as it rapidly weakened and transitioned into an extra-tropical low.

III. IMPACT

As Robyn moved southwest of Guam, it provided some relief for the drought-stricken island. Typhoon Robyn caused Condition of Readiness (COR) 1 to be set at Ulithi and Yap. JTWC forecasters expected the system to turn northward, but that the timing could not be determined accurately enough to keep Yap from setting COR 1. After passing to the north of Ulithi and Yap, Robyn (Figure 3-13-1) headed for the Ryukyu Islands. Kadena AB, on Okinawa evacuated aircraft and went to COR 1 at 080300Z. Peak winds recorded on Okinawa were 43 kt (22 m/sec). Subsequently, Robyn tracked across Kyushu, causing the Naval Station at Sasebo, Japan to set COR 1. As Robyn passed just west of the Sasebo, a ship in the harbor, the MV Maersk Constellation, reported sustained winds of 60-65 kt (31-33 m/sec) and a barometric pressure of 973 mb at 091800Z. The ship's pressure fell to a minimum of 969.0 mb at 092200Z. During the ordeal, the ship dragged anchor for half a mile across the harbor. In contrast, the Sasebo weather station which is sheltered by hills only reported maximum sustained winds of 40-48 kt (21-25 m/sec) with gusts to 60 kt (31m/sec). Later, as Robyn passed though the Korea Strait, it created 20-35 ft (6.1-10.7 m) waves on the southern coast of Korea. Coastal wave damage and agricultural losses due to flooding amounted to more than (US)$68 million. Of the over 45 storm-related deaths, press reports indicated 39 resulted from automobile accidents attributed to the torrential rains.

IV. DISCUSSION

The JTWC-based, month-long TCM-93 was in progress when Robyn began developing. The experiment team was using a WC-130 weather reconnaissance aircraft to test hypotheses involving sub-synoptic and mesoscale effects on tropical cyclone motion. In the case of Robyn, the team planned to test the hypothesis of Holland and Lander (H&L) (1993) that large mesoscale convective systems (MCS) embedded in the tropical cyclone circulation can cause meanders in tropical cyclone tracks on the order of 100 km over a period of 1-2 days. H&L's physical explanation for this is that an MCS develops sufficient vorticity, allowing it to rotate cyclonically with the tropical cyclone about a centroid between the two, in a manner similar to that observed during a Fujiwhara (or binary) interaction between two independent tropical cyclones. At 1230Z on the night of 03 August, a band of convection began to build about 100 nm (185 km) north of Robyn's central dense overcast (CDO). In two hours, a portion of the band had explosively expanded into a large elliptical MCS of comparable size to Robyn's CDO (Figure 3-13-2). Over the 9-hour period from 031500Z to 040000Z, the large MCS rapidly moved 300 nm (555 km) westward (from an initial location to the north of Robyn to a later position to the northwest of Robyn), at a speed of 34 kt (63 km/hr). During the same 9-hour period, Robyn slowed in forward speed from 13 kt (24 km/hr) to 6 kt (11 km/hr). After the MCS moved to the west side of Robyn, the typhoon's track, at least in the animated satellite imagery, appeared to cease all westward movement, take a small dip to the south, and then reverse direction, heading to the north and then the northwest.

This abrupt track change required less than 6 hours. The sequence of events concerning Typhoon Robyn are discussed in more detail in Harr et. al (1993).

Another plausible explanation for the unusual motion of Robyn has been postulated by Carr and Elsberry (C&E) (1994), who attributed the behavior to the interaction of Robyn with a large "monsoon gyre" located to its west. In sensitivity studies using a barotropic model, C&E were able to duplicate the character of Robyn's abrupt track changes — westward motion followed by an abrupt change to northward or northwestward motion. Figure 3-13-3 illustrates the sudden track changes exhibited by 6 tropical cyclones in 1990. It is conceivable that both the MCS and monsoon gyre mechanisms may have been working in tandem to produce Robyn's abrupt track change.

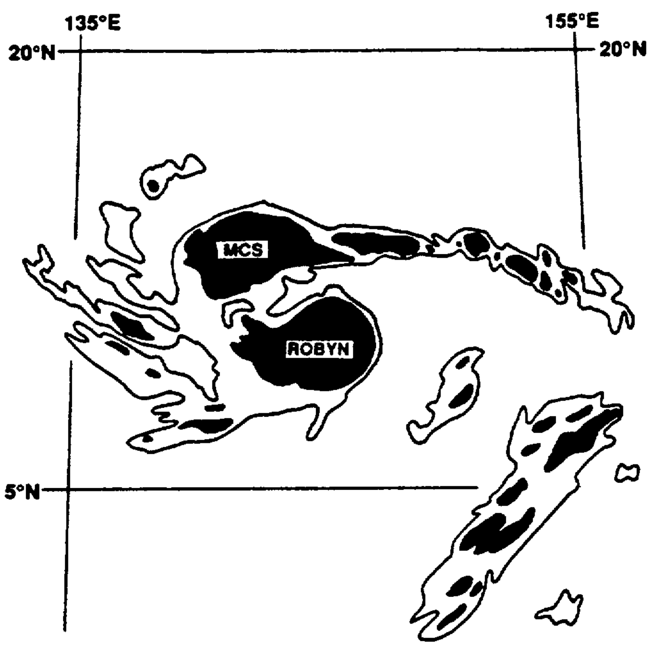


Figure 3-13-2 Graphic representation of the observed cold cloudiness associated with Robyn's CDO and an MCS. Solid black cloud silhouettes represent areas of coldest convective tops, outer contours shows regions of dense cirrus overcast. (Adapted from 031531Z August enhanced infrared GMS imagery.)

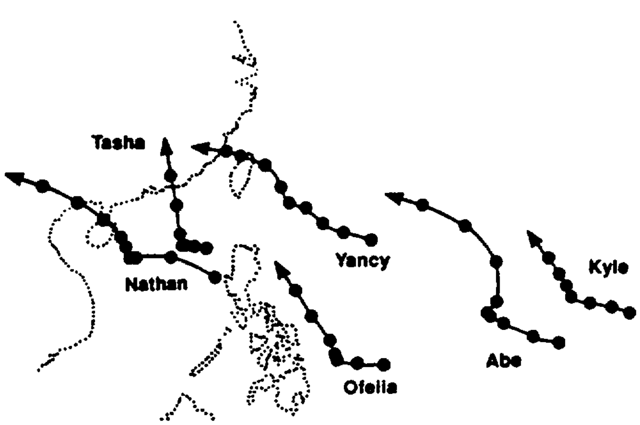
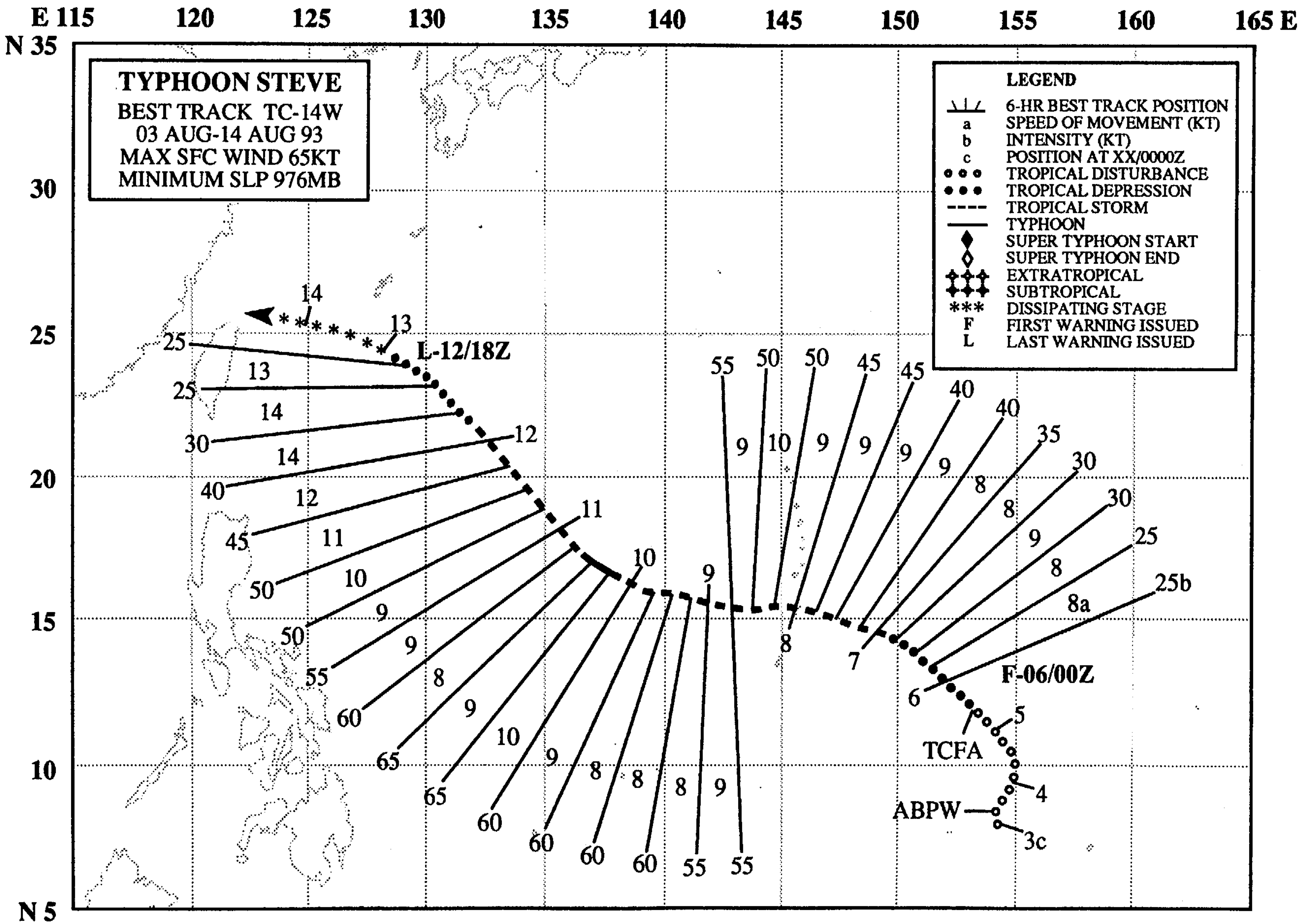


Figure 3-13-3 A composite of 3-4 day track segments centered around sudden below-the-ridge track changes for 6 tropical cyclones in 1990 (from Carr and Elsberry, 1994).


TYPHOON STEVE
BEST TRACK TC-14W
03 AUG-14 AUG 93
MAX SFC WIND 65KT
MINIMUM SLP 976MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135
140
145
150
155
160
165 E
N 35
30
25
20
15
10
N 5
L-12/18Z
F-06/00Z
TCFA
ABPW
3c
25b
8a

TYPHOON STEVE (14W)

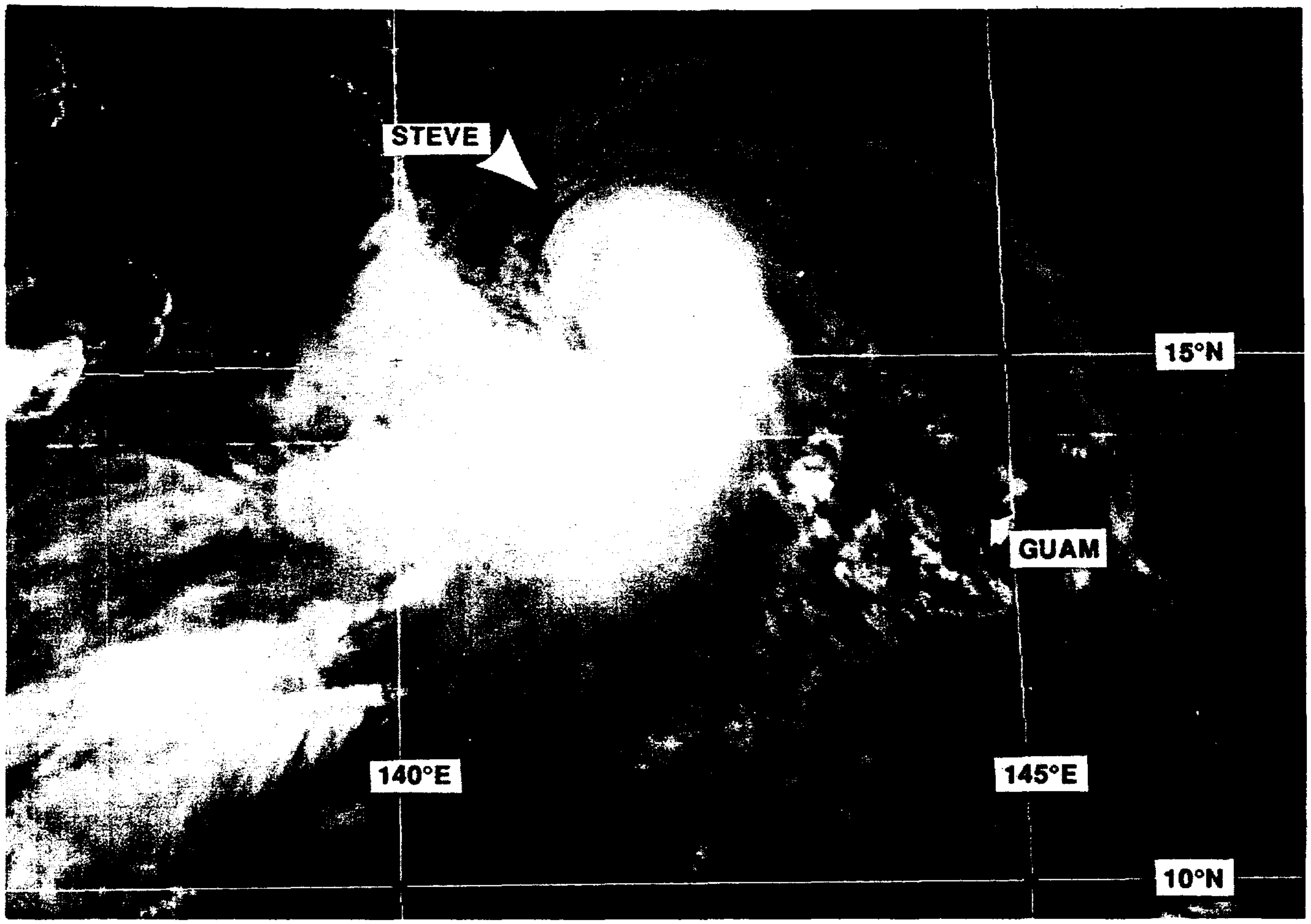


Figure 3-14-1 To the northwest of Guam, Steve continues to slowly intensify (082331Z August visual GMS imagery).

I. HIGHLIGHTS

Forming in the wake of, Robyn (13W), Steve became the second tropical cyclone of August. Despite the appearance of strong upper-level westerly wind shear from Robyn's outflow, Steve was able to attain minimal typhoon intensity. Later, however, the typhoon was subjected to strong easterly shear and rapidly dissipated over the open ocean south of Okinawa.

I. CHRONOLOGY OF EVENTS

August

030600Z - The tropical disturbance was first mentioned on the Significant Tropical Weather advisory as an area of persistent convection enhanced by a surge in the southwest monsoon.

051300Z - The appearance of a developing cyclonic circulation on the animated cloud imagery prompted the issuance of a Tropical Cyclone Formation Alert.

060000Z - The first warning was issued based on the improved organization of the convection as viewed on the the first visual satellite image of the day.

070000Z - Steve was upgraded to tropical storm intensity based on improved convective organization and the resulting 35-kt (13-m/sec) satellite intensity estimate.

080835Z - Warning responsibility transferred to the Alternate Joint Typhoon Warning Center at Pearl Harbor, Hawaii after an 8.1 magnitude earthquake near Guam temporarily knocked out power and communications.
081800Z - Warning responsibility returns to JTWC.
100600Z - Steve was upgraded to typhoon intensity based on the appearance of a cloud-filled eye.
121800Z - The final warning was issued on Steve following rapid dissipation over water in an environment featuring strong upper-level easterly winds.

III. IMPACT

Tropical Storm Steve caused Saipan and Tinian to go to Condition of Readiness (COR) 1. Saipan recorded sustained winds of 45 kt (23 m/sec) with gusts to 60 kt (31 m/sec) and experienced extensive flooding on the island due to heavy rains on 8 August. The large PACOM combined exercise, TANDEM THRUST, was prematurely ended when troops prepositioned on the island of Tinian were evacuated and a planned amphibious assault of the island was canceled due Steve's approach.

IV. DISCUSSION

As Steve developed and moved westward, it came under the upper-level outflow of Typhoon Robyn (13W). Despite the appearance of strong upper-level wind shear, Steve managed to continue to slowly intensify. As Robyn moved northwestward toward the Ryukyu Islands, the upper-level shear appeared to weaken as Steve slowly intensified (Figure 3-14-1). On the afternoon of 10 August, Steve was upgraded to typhoon intensity and coincidently made a track change from westward to northwestward. After reaching minimal typhoon intensity, Steve began to weaken apparently in association with the establishment of northeasterly flow aloft. This flow became established as Robyn recurved into midlatitudes and a large upper-level anticyclone formed east of Japan.

It is interesting to note that Steve intensified slowly in an environment that featured upper-level westerly winds, but weakened rapidly in an environment that featured upper-level northeasterly winds. A closer look at these two upper-level wind regimes follows.

a. Intensification despite westerly wind shear — Steve comes under the influence of the outflow from Typhoon Robyn. The fact that Steve is able to maintain a central dense overcast (CDO), suggests that the system's own outflow is able to hold its own against that of Robyn's, thus deflecting the westerly winds and preventing the shear from reaching the central core. It is suggested that in order for Steve to survive, its outflow has to maintain a buffer sufficient to keep the westerly winds from disrupting the vertical structure of the core of the storm. The deflection of the westerly upper-level winds around Steve's cloud system may not be as difficult as it would appear at first glance. The wind at 200 mb near Robyn was strongly cyclonic for a radius of several hundred miles. Thus, the upper-level westerly winds (as indicated by the orientation of the cirrus cloud plumes) in the vicinity of Steve — located downstream from Robyn's outflow to the east — were probably relatively high and relatively shallow. The thinness of the ambient cirrus is further evidence that the upper-level westerly flow over Steve was relatively high (at the 200-mb pressure height and higher) and shallow (confined between the 200-mb level upward to just above the tropopause). The relatively straight-line westerly winds from the high-level outflow streaming from Robyn and across the region of Steve lasted for three days (5-7 August) in the manner illustrated in the model in Figure 3-14-2a. There was a gradual shrinking of the convection in response to the shear during those three days (Figure 3-14-3a). By 8 August, the upper-level flow had become strongly diffluent in the region of Steve, flowing northward into a cell in the TUTT to the northwest of Steve, and turning anticyclonically into strong easterlies south of Steve. This diffluent pattern is illustrated in the synoptic model in Figure 3-14-2b. Steve was thus placed in an area of maximum anticyclonic curvature which not only reduced the shear above the storm, but also placed Steve in a region of upper-level divergence — two factors commonly believed to be favorable for intensification. While all the shear was probably not eradicated, it was sufficiently reduced for a long-enough period of time to allow Steve to survive, and to grow in size and intensity as illustrated by the size of the cirrus shield in Figure 3-14-3b.

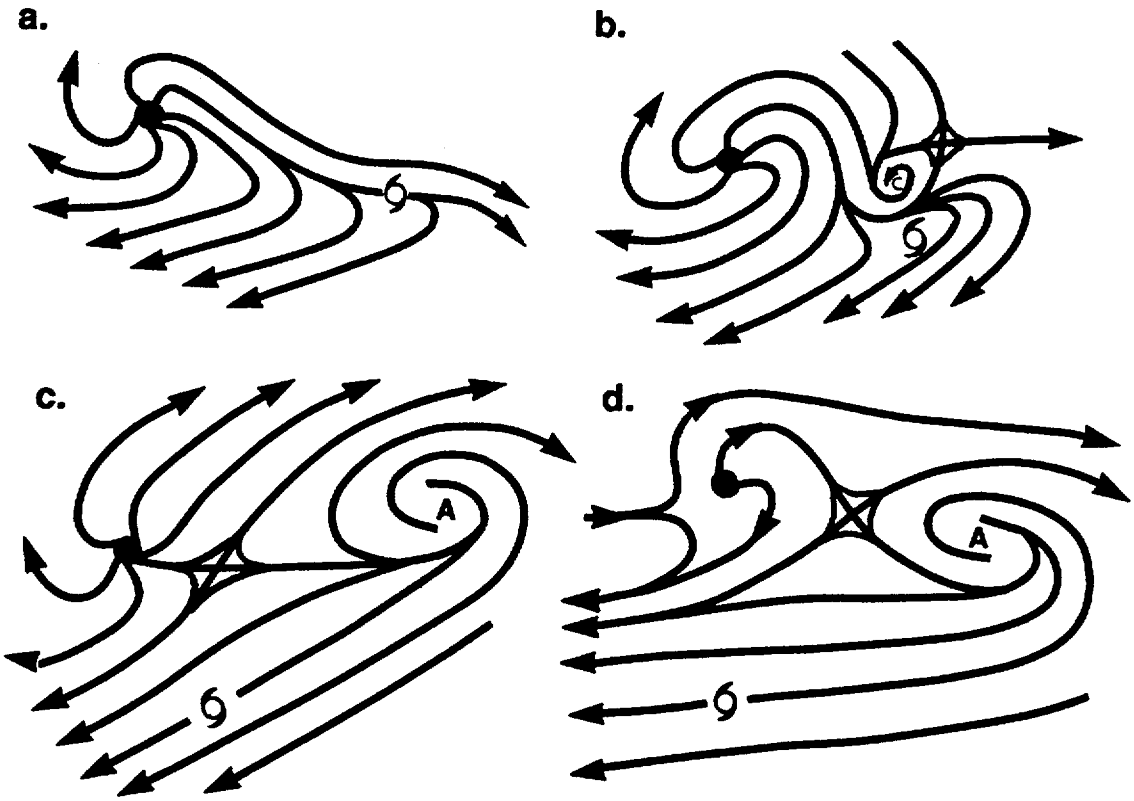


Figure 3-14-2 A model of upper-level streamlines based on composited 200-mb winds and cirrus plume orientations taken from satellite imagery associated with Robyn (13W) and Steve: (a) Composite for 5 through 7 August, (b) Composite for 8 through 10 August, (c) Composite for 10 and 11 August, and (d) Composite for 12 and 13 August. Solid black dot = the location of Robyn and tropical cyclone symbol = Steve.

b. Weakening with Strong Upper-Level Easterly Winds — In this case, the ambient flow is deep and non-diffluent easterly with speed increasing with height (Figure 3-14-2c and d). The easterly winds also act to block any outflow to the poleward side of the storm. The result is no intensification and eventual weakening. It is common to observe the decoupling of the convection and the low-level circulation, with the convection going in one direction and the exposed low-level circulation center going in another, as was observed with Steve. While subjected to strong upper-level northeasterly wind (later veering to easterly), the size of Steve's cirrus shield rapidly shrank (Figure 3-14-3c). Steve could not maintain its vertical structure against easterly winds aloft.

c. Rules of Thumb — 1) Upper-level westerly or southwesterly winds from a tropical cyclone can create a downstream environment to the east that is favorable for the development or intensification of another tropical cyclone, despite the appearance (on satellite imagery) of strong westerly shear across the downstream tropical cyclone. The upper-level westerly winds are generally in a shallow layer, high, and strongly diffluent. Convection is favored at the location of the second (or downstream) tropical cyclone as a quasi-stationary trough amplifies in the upper-level flow between the two tropical cyclones. 2) In contrast, strong easterly or northeasterly upper-level winds across a tropical cyclone tend to shear away the convection leaving the low-level circulation center exposed.

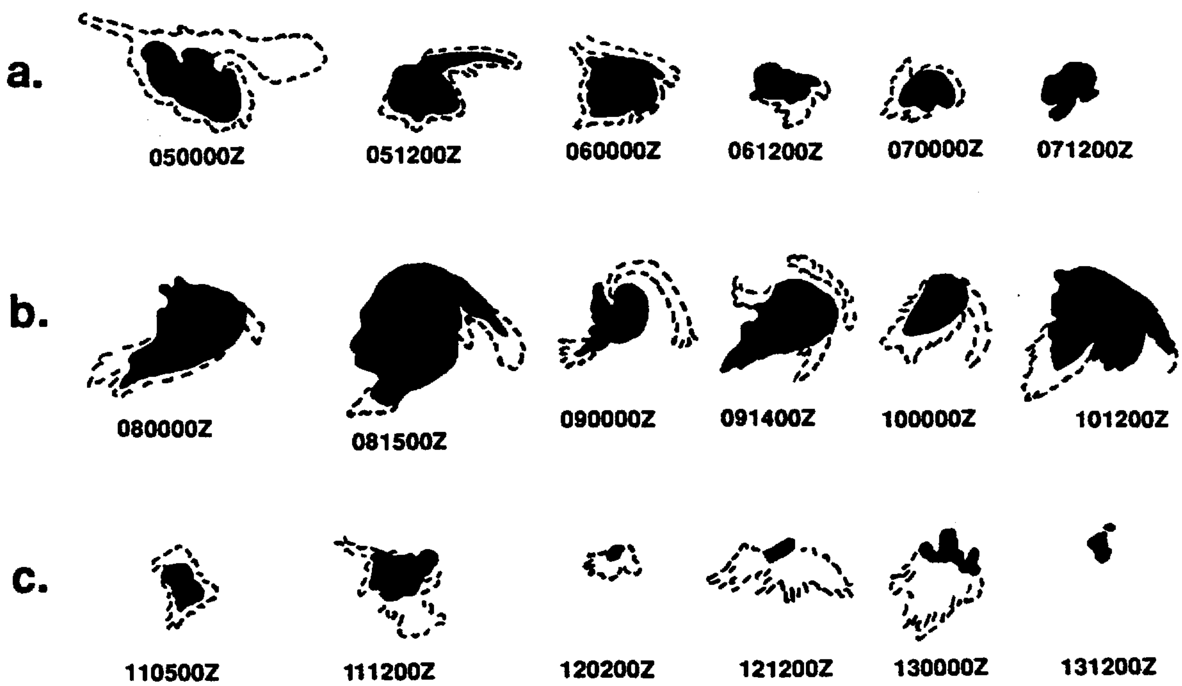
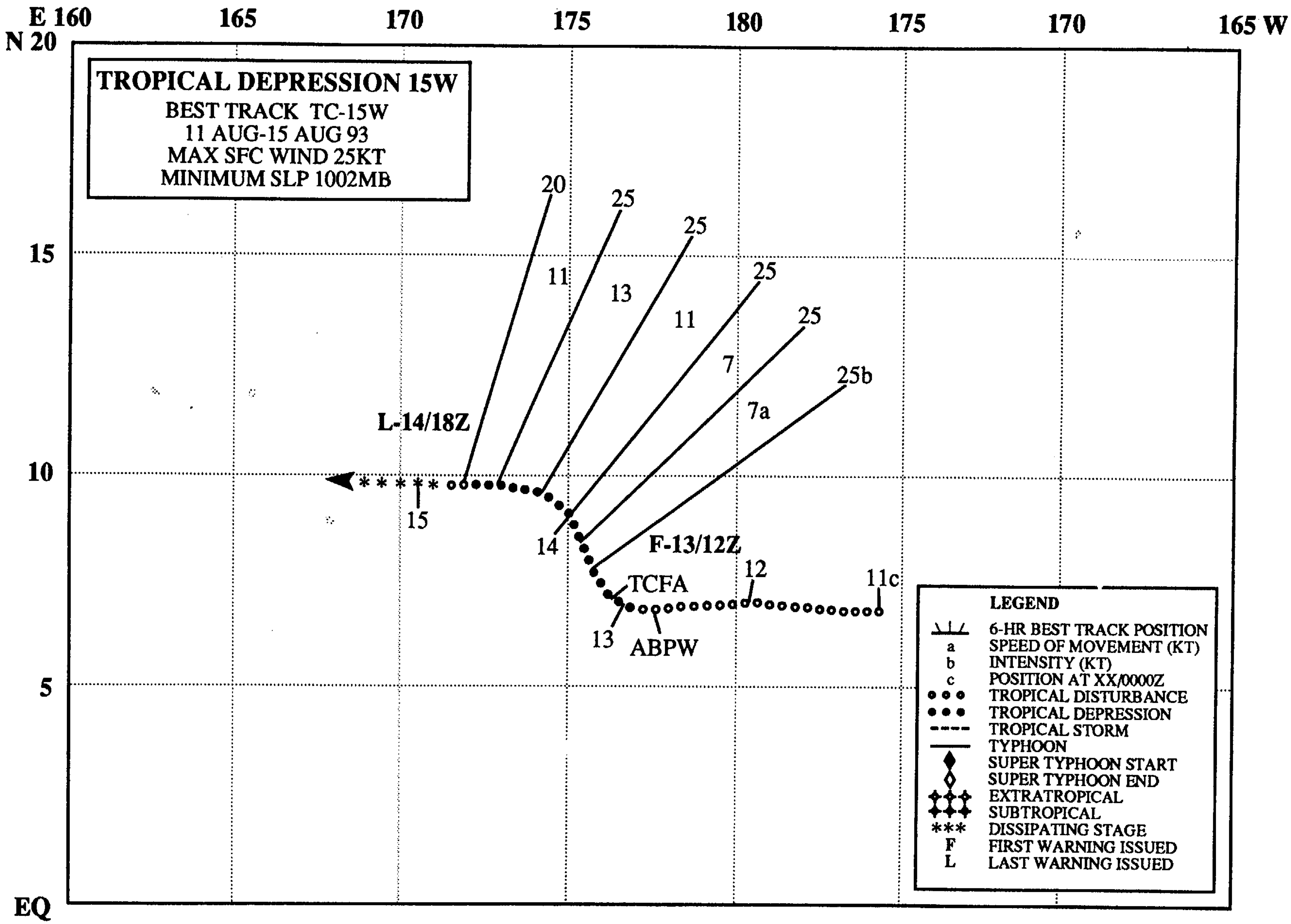


Figure 3-14-3 Illustration depicting the size and shape of Steve's cirrus canopy from 5 to 13 August: (a) unidirectional westerly winds aloft, (b) highly diffluent west winds aloft, and (c) unidirectional easterly winds aloft. Black areas = dense cirrus overcast and dashed lines = the extent of thin cirrus.



TROPICAL DEPRESSION 15W
BEST TRACK TC-15W
11 AUG-15 AUG 93
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
E 160
165
170
175
180
175
170
165 W
N 20
15
10
5
EQ
L-14/18Z
F-13/12Z
TCFA
ABPW
20
25
25
25
25
25b
11
13
11
7
7a
15
14
13
12
11c
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL DEPRESSION 15W

I. HIGHLIGHTS

Forming near the international date line, Tropical Depression 15W was hindered by persistent upper-level wind shear resulting in a short-lived system which, like Tropical Depression 01W earlier, required only five warnings (Figure 3-15-1).

II. CHRONOLOGY OF EVENTS

August

121800Z - When the convection associated with the disturbance increased, the Significant Tropical Weather Advisory was reissued to include the disturbance as a fair suspect area.

130300Z - A Tropical Cyclone Formation Alert was issued following an increase in convective organization.

131200Z - Based on a satellite intensity estimate of 25 kt (13 m/sec), JTWC issued the first warning.

141800Z - The final warning was issued as the depression dissipated due to persistent upper level shear which left behind an exposed low-level circulation.

III. IMPACT

None.

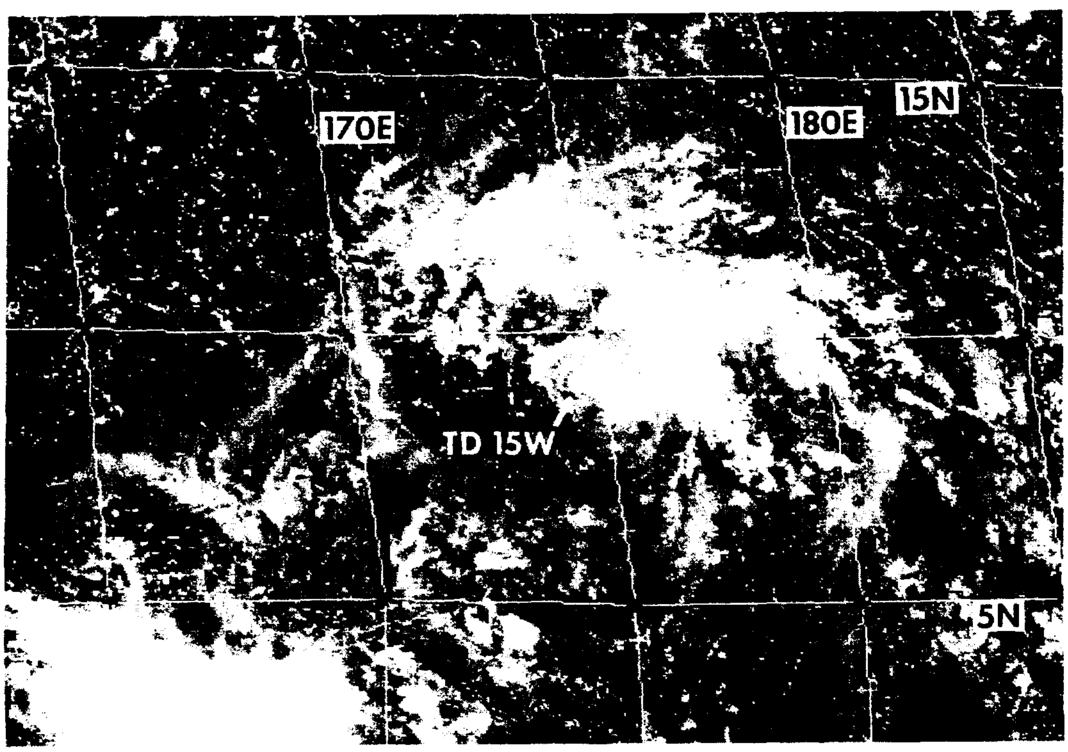
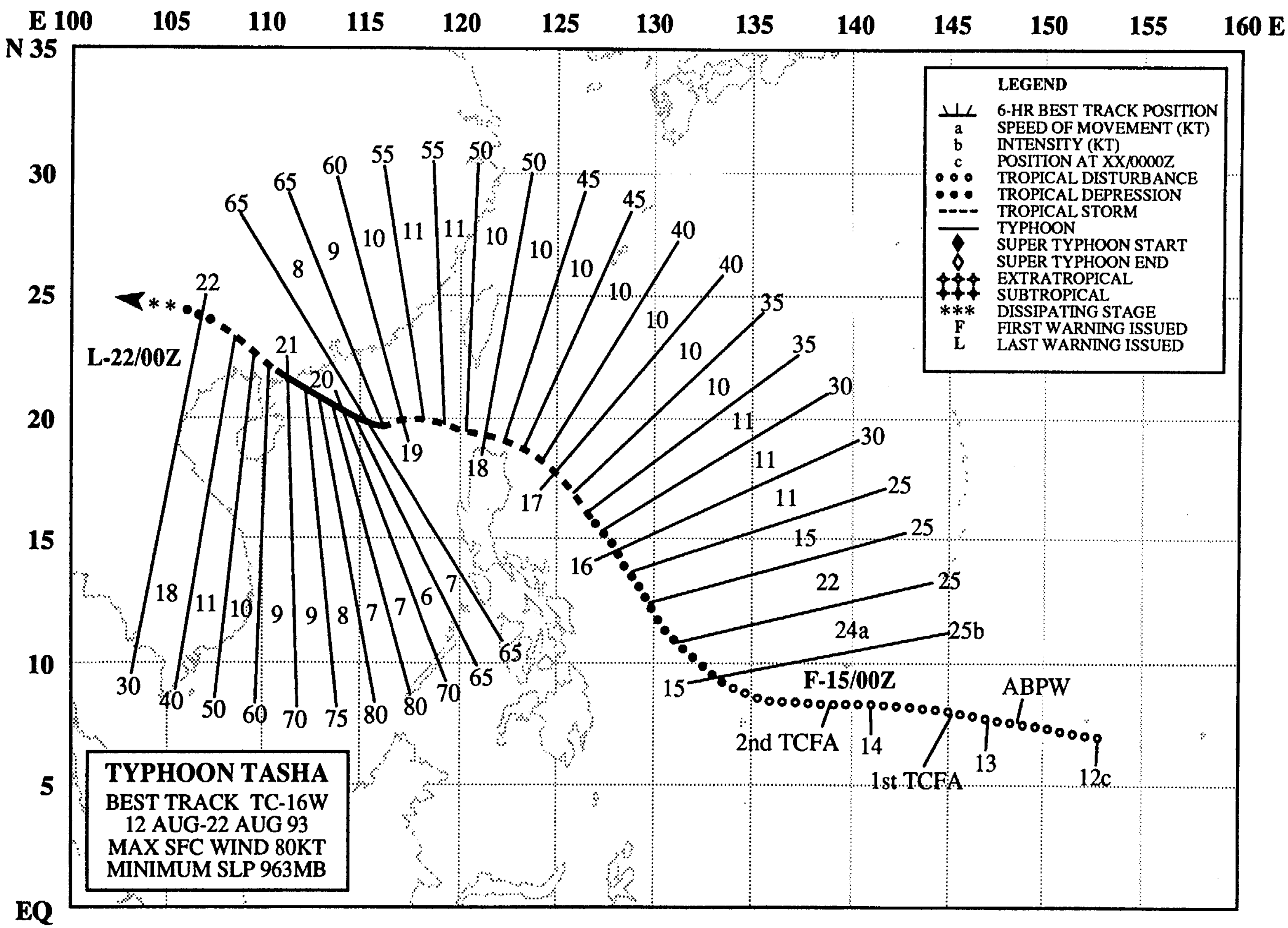


Figure 3-15-1 Convection associated with TD 15W is persistent, but remains poorly organized (140231Z August visual GMS imagery).


E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-22/00Z
F-15/00Z
ABPW
2nd TCFA
1st TCFA
12c
13
14
15
16
17
18
19
20
21
22
24a
25b
TYPHOON TASHA
BEST TRACK TC-16W
12 AUG-22 AUG 93
MAX SFC WIND 80KT
MINIMUM SLP 963MB

TYPHOON TASHA (16W)

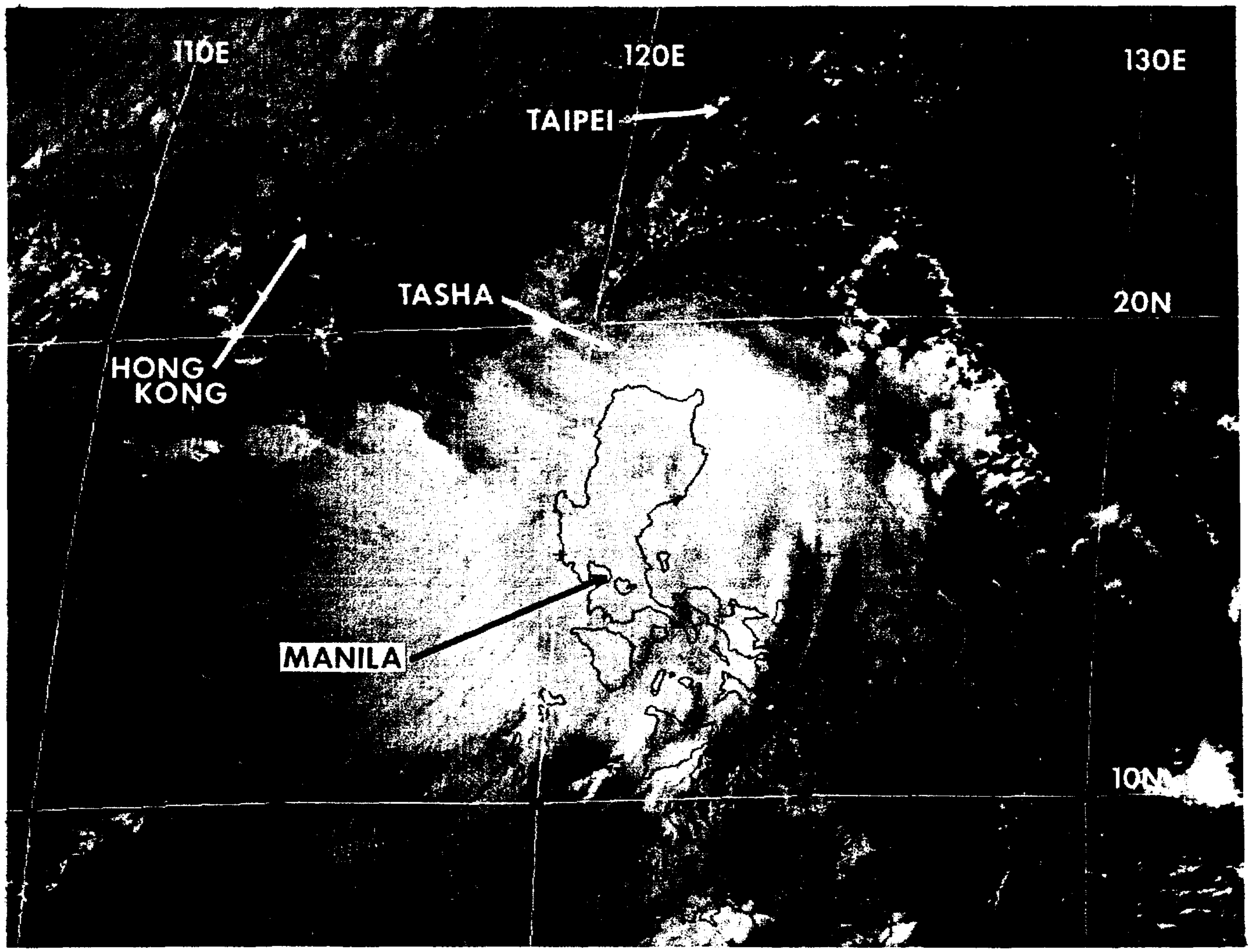


Figure 3-16-1 As Tasha passes north of Manila, bands of deep convection cover the island of Luzon (172331Z August visual GMS imagery.)

I. HIGHLIGHTS

Forming within the monsoon trough near Chuuk in the central Caroline Islands, Tasha was the fourth significant tropical cyclone of August. Tasha intensified slowly, but steadily, as it tracked northwestward across the Philippine Sea and into the South China Sea where it briefly threatened Hong Kong.

II. CHRONOLOGY OF EVENTS

August

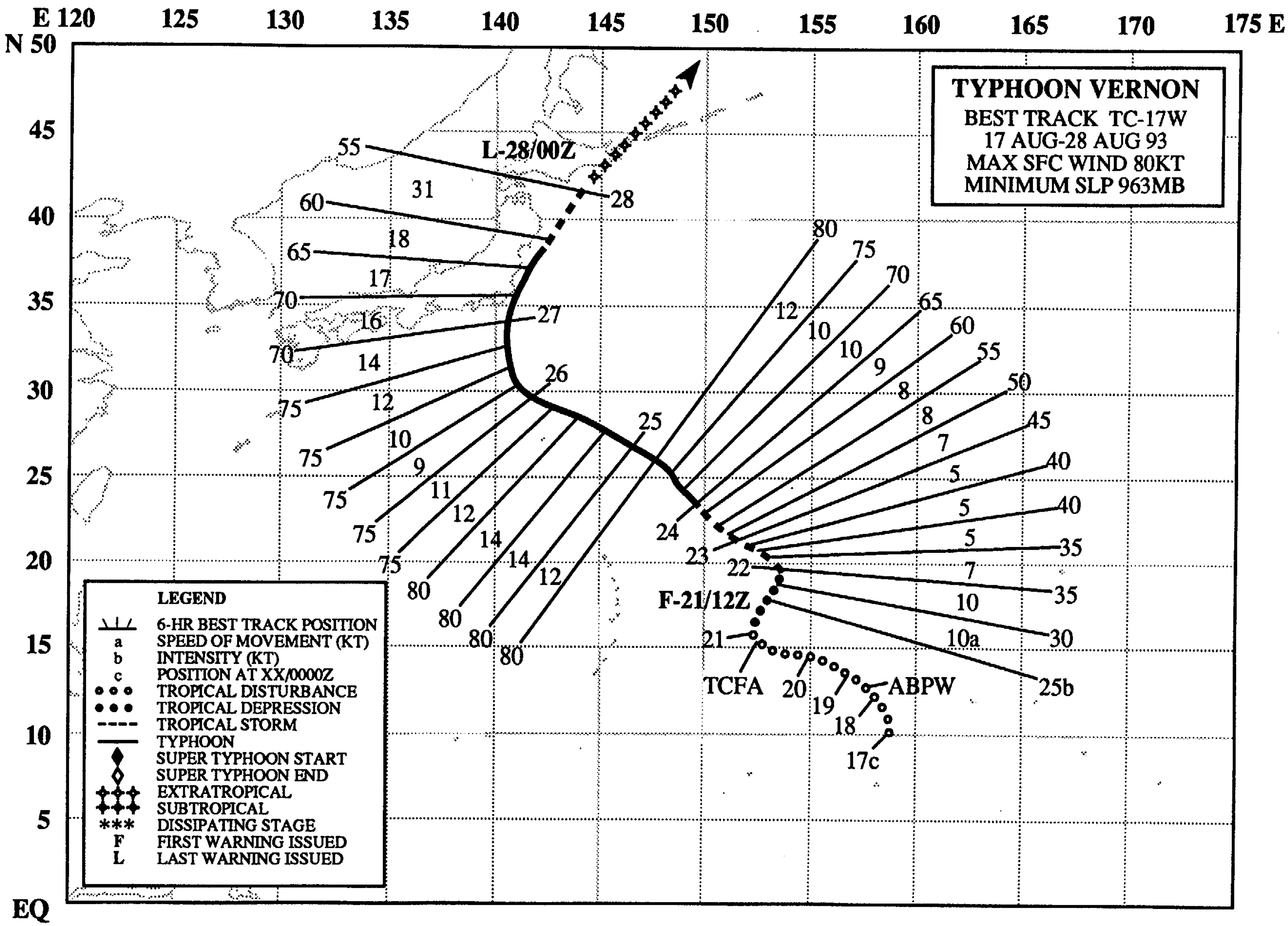
121800Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection embedded within the monsoon trough.

130800Z - The first Tropical Cyclone Formation Alert (TCFA) was issued based on an increase in convection.

140800Z - While the disturbance did not intensify significantly during the first TCFA, conditions remained favorable for development, and a second TCFA was issued.
150000Z - The first warning was issued based on gradient-level winds of 31 kt (16 m/sec) at Koror (WMO 91408).
161200Z - Based upon increased convective curvature and a satellite intensity estimate of 35 kt (18 m/sec), Tasha was upgraded to a tropical storm.
190600Z - Following a satellite intensity estimate of 65 kt (33 m/sec) which also indicated that upper-level shear had abated, Tasha was upgraded to a typhoon.
220000Z - The final warning was issued as the tropical cyclone dissipating over land in southern China.

III. IMPACT

Flooding from heavy rains associated with Tasha (Figure 3-16-1) as it passed north of Luzon, forced 21,000 people to evacuate homes in low-lying areas in Manila.


TYPHOON VERNON
BEST TRACK TC-17W
17 AUG-28 AUG 93
MAX SFC WIND 80KT
MINIMUM SLP 963MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-28/00Z
F-21/12Z
TCFA
ABPW
E 120
125
130
135
140
145
150
155
160
165
170
175 E
N 50
45
40
35
30
25
20
15
10
5
EQ

TYPHOON VERNON (17W)

I. HIGHLIGHTS

Vernon formed east of the Mariana Islands as Typhoon Keoni (01C) was moving over open water to the northeast and Typhoon Tasha (16W) was moving inland over China. Threatening Japan, Vernon passed to the east of Tokyo as it skirted the east coast of Honshu. Vernon continued towards the north-northeast where it slowly weakened and eventually transitioned into an extratropical low in the Sea of Okhotsk.

II.CHRONOLOGY OF EVENTS

August

180600Z - Vernon was first mentioned in the Significant Tropical Weather Advisory as an extensive area of convection within the monsoon trough north of Pohnpei.

201700Z - Increased convection, associated with the disturbance, led to the issuance of a Tropical Cyclone Formation Alert.

211200Z - The first warning was issued based on increased convective curvature and a satellite intensity estimate of 25 kt (13 m/sec).

220000Z - Vernon was upgraded to tropical storm intensity following a satellite estimate of 35 kt (18 m/sec).

240000Z - A satellite intensity estimate of 65 kt (33 m/sec) was the impetus for upgrading Vernon to a typhoon (Figure 3-17-1).

280000Z - The final warning was issued as Vernon transitioned into an extratropical low in the Sea of Okhotsk.

III. IMPACT

Japanese news agencies reported two deaths and four injuries. More than 7800 homes and businesses were flooded. There were also numerous landslides, and washed out bridges, roads, and railways. The Naval Meteorology and Oceanography Command Facility at Yokosuka reported maximum sustained winds of 45 kt gusting to 62 kt (23G32 m/sec). Further from Vernon's track and inland, the Naval Meteorology and Oceanography Command Detachment at Atsugi observed maximum sustained winds of 35 kt gusting to 49 kt (18G25 m/sec).

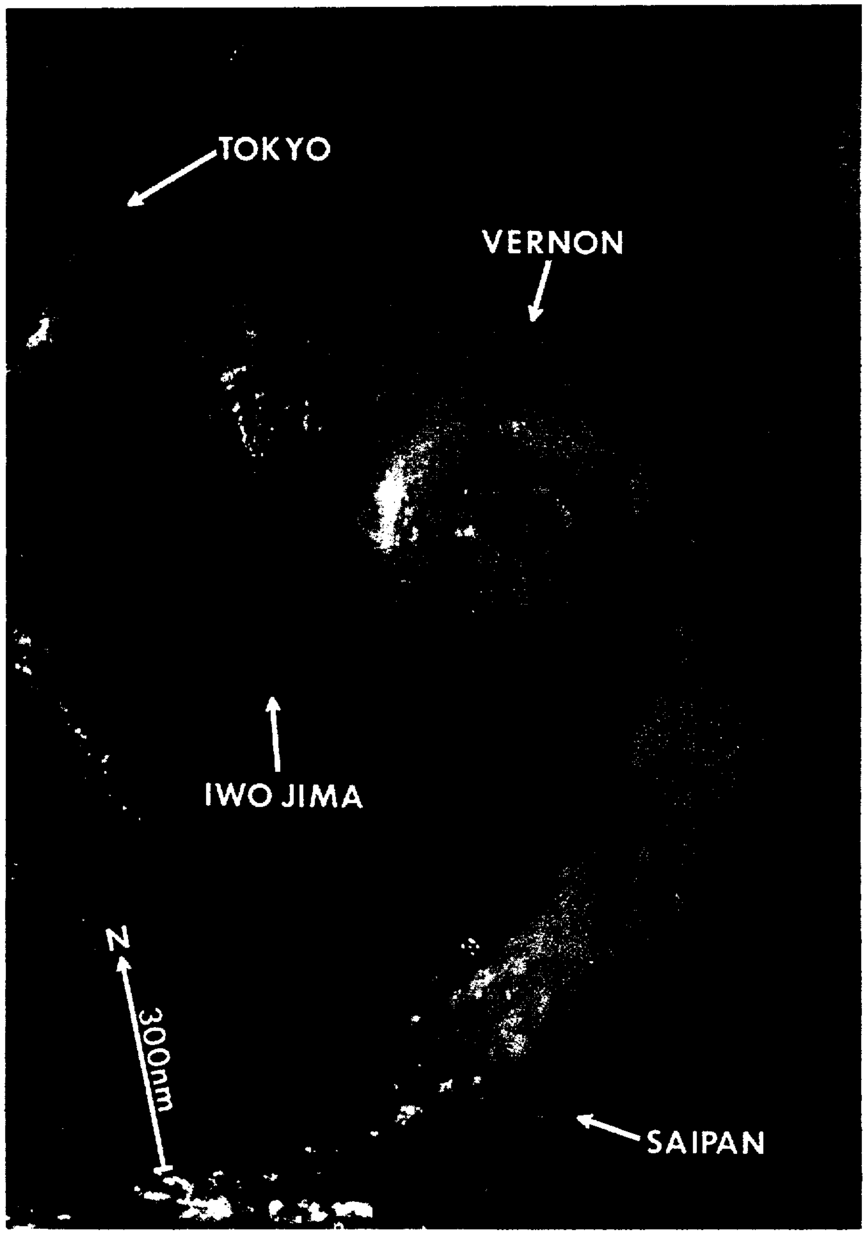
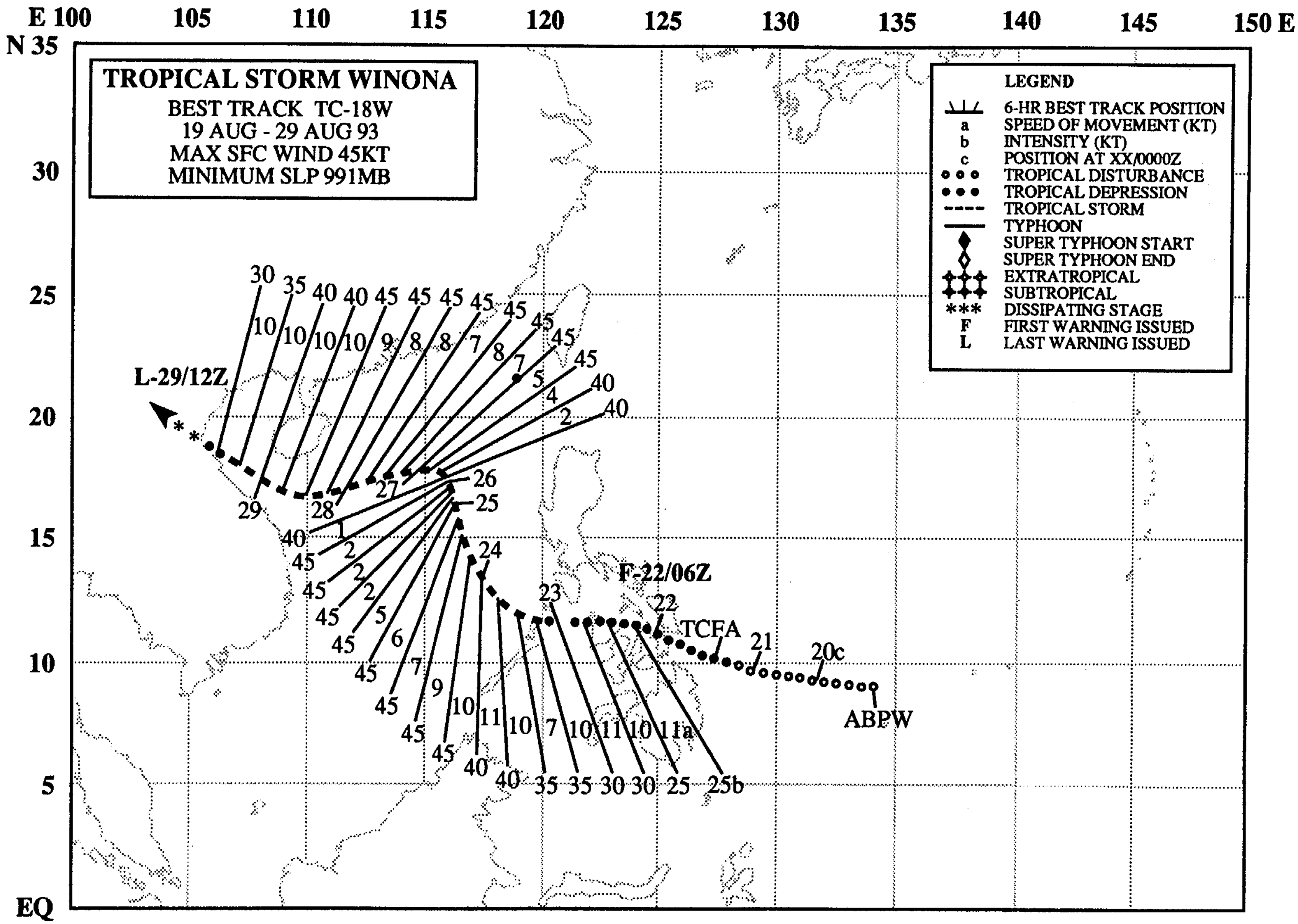


Figure 3-17-1 Typhoon Vernon, a day after reaching its peak intensity, heads toward Tokyo. Part of Keoni's (01C) cloud shield appears in the top right corner of the picture (250021Z August visual DMSP imagery).


TROPICAL STORM WINONA
BEST TRACK TC-18W
19 AUG - 29 AUG 93
MAX SFC WIND 45KT
MINIMUM SLP 991MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145
150 E
N 35
30
25
20
15
10
5
EQ
L-29/12Z
F-22/06Z
TCFA
ABPW
20c
21
22
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27
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29
25b

TROPICAL STORM WINONA (18W)

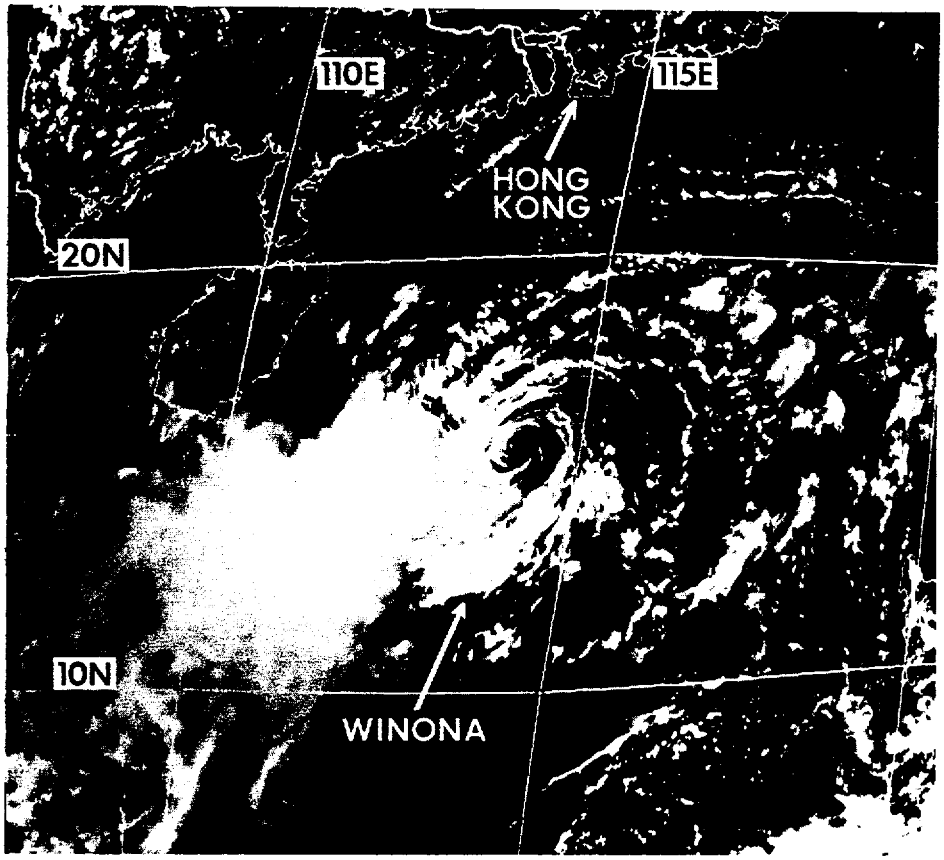


Figure 3-18-1 Convection displaced to the southwest, by strong upper tropospheric winds, fully exposes the low-level circulation center of Tropical Storm Winona (242330Z August visual GMS imagery).

I. HIGHLIGHTS

Initially forming west of Palau in the Philippine Sea, Winona slowly intensified while crossing the central Philippine Islands. Upon entering the South China Sea, Winona continued to slowly intensify, but reached an intensity plateau of 40 to 45 kt (20 to 23 m/sec) that lasted for four days. Increasing upper tropospheric wind shear weakened the storm as it moved westward (Figure 3-18-1). Winona ultimately moved over Vietnam and dissipated.

II. CHRONOLOGY OF EVENTS

August

190600Z - Persistent convection within the monsoon trough, near the western Caroline Islands, resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

211200Z - A Tropical Cyclone Formation Alert was issued following an increase in convective organization.

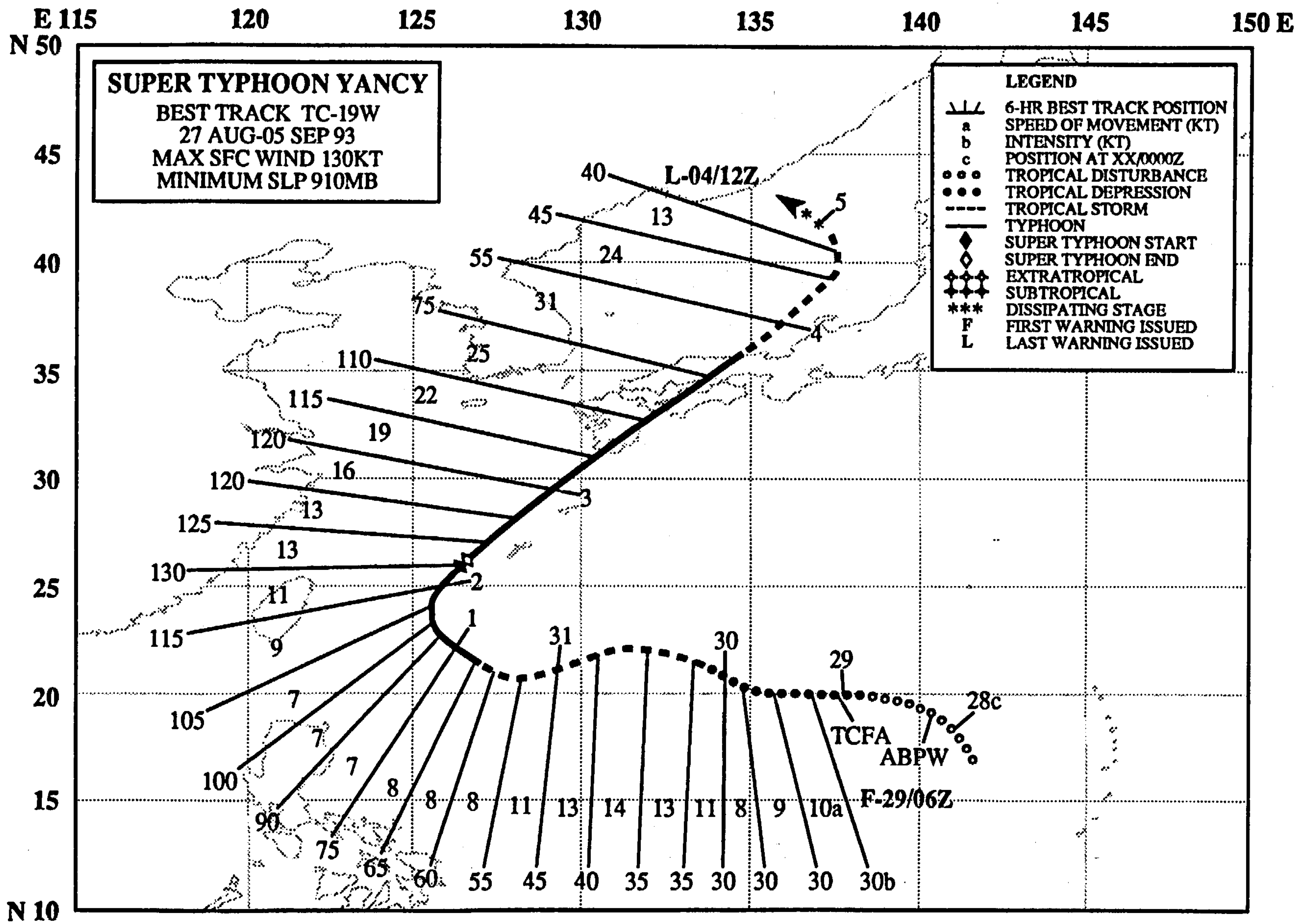
220600Z - The first warning was issued based on increased convective curvature and a satellite intensity estimate of 25 kt (13 m/sec).

230600Z - Following a satellite intensity estimate of 35 kt (18 m/sec),
Winona was upgraded to tropical storm intensity.

291200Z - The final warning was issued on Winona as it dissipated over Vietnam.

III. IMPACT

No reports were received.


SUPER TYPHOON YANCY
BEST TRACK TC-19W
27 AUG-05 SEP 93
MAX SFC WIND 130KT
MINIMUM SLP 910MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 115
120
125
130
135
140
145
150 E
N 50
45
40
35
30
25
20
15
N 10
L-04/12Z
F-29/06Z
TCFA
ABPW
28c
10a
30b

SUPER TYPHOON YANCY (19W)

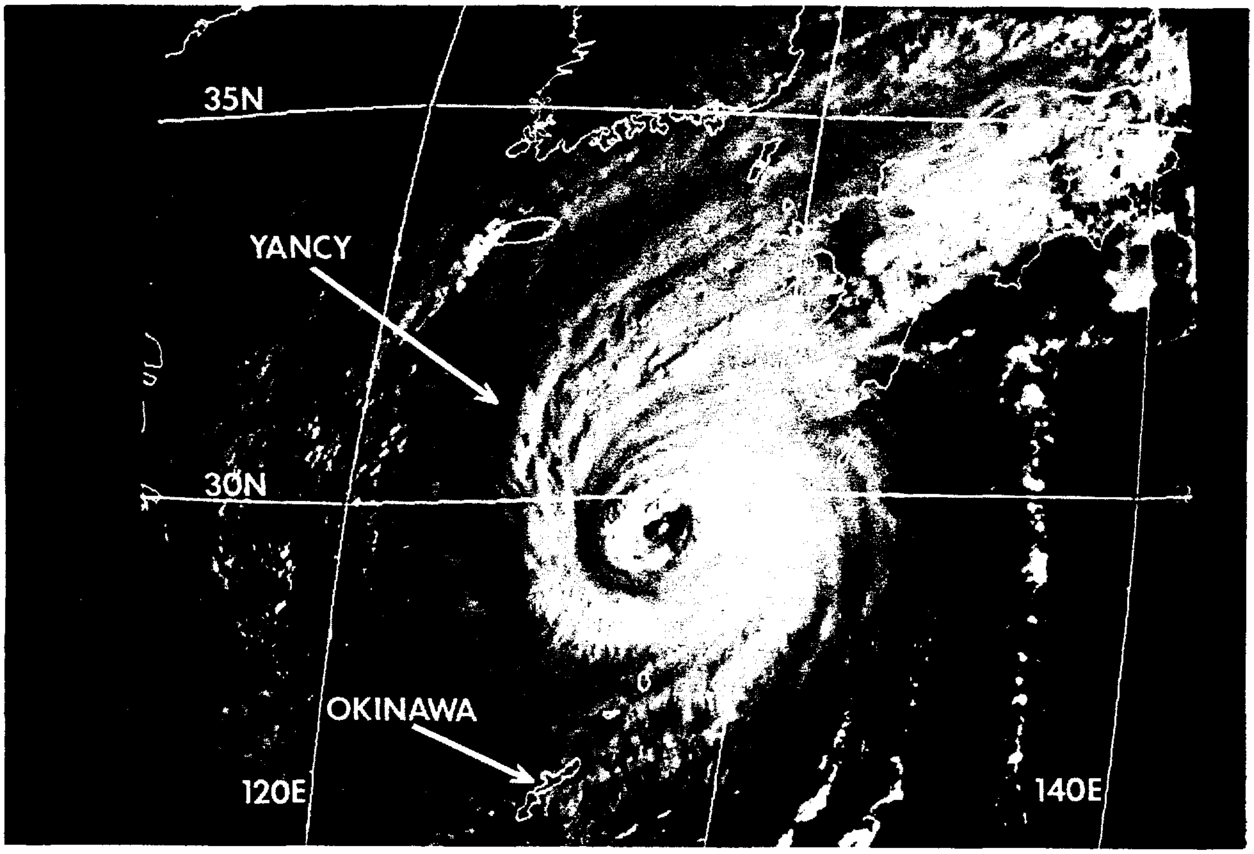


Figure 3-19-1 Visual image of Super Typhoon Yancy with a large, elongated eye, approximately seven hours prior to landfall in southern Kyushu. At this time, Yancy's maximum sustained winds were estimated to be 120 kt (62 m/sec) (022330Z September visual GMS imagery.)

I. HIGHLIGHTS

Striking southern Kyushu with sustained winds of 115 kt (60 m/sec), Yancy was one of the most powerful typhoons to hit Japan in decades (Figure 3-19-1). Forming in the Philippine Sea, Yancy tracked westward toward Taiwan, until it reached typhoon intensity. The tropical cylone then turned to the northeast and rapidly intensified into a super typhoon, passing within 60 nm (110 km) of Okinawa. Yancy was the second of three super typhoons of the 1993 tropical cyclone season.

II. CHRONOLOGY OF EVENTS

August

280600Z - An area of persistent convection generated by convergent southwesterly monsoonal flow resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

290100Z - A Tropical Cyclone Formation Alert was issued on the disturbance when convection consolidated near the circulation center.

290600Z - The first warning was issued based on a satellite intensity estimate of 25 kt (13 m/sec).

300600Z - Based on a ship report of 40 kt (21 m/sec) 60 nm (110 km) east of the system center, Yancy was upgraded to tropical storm intensity.

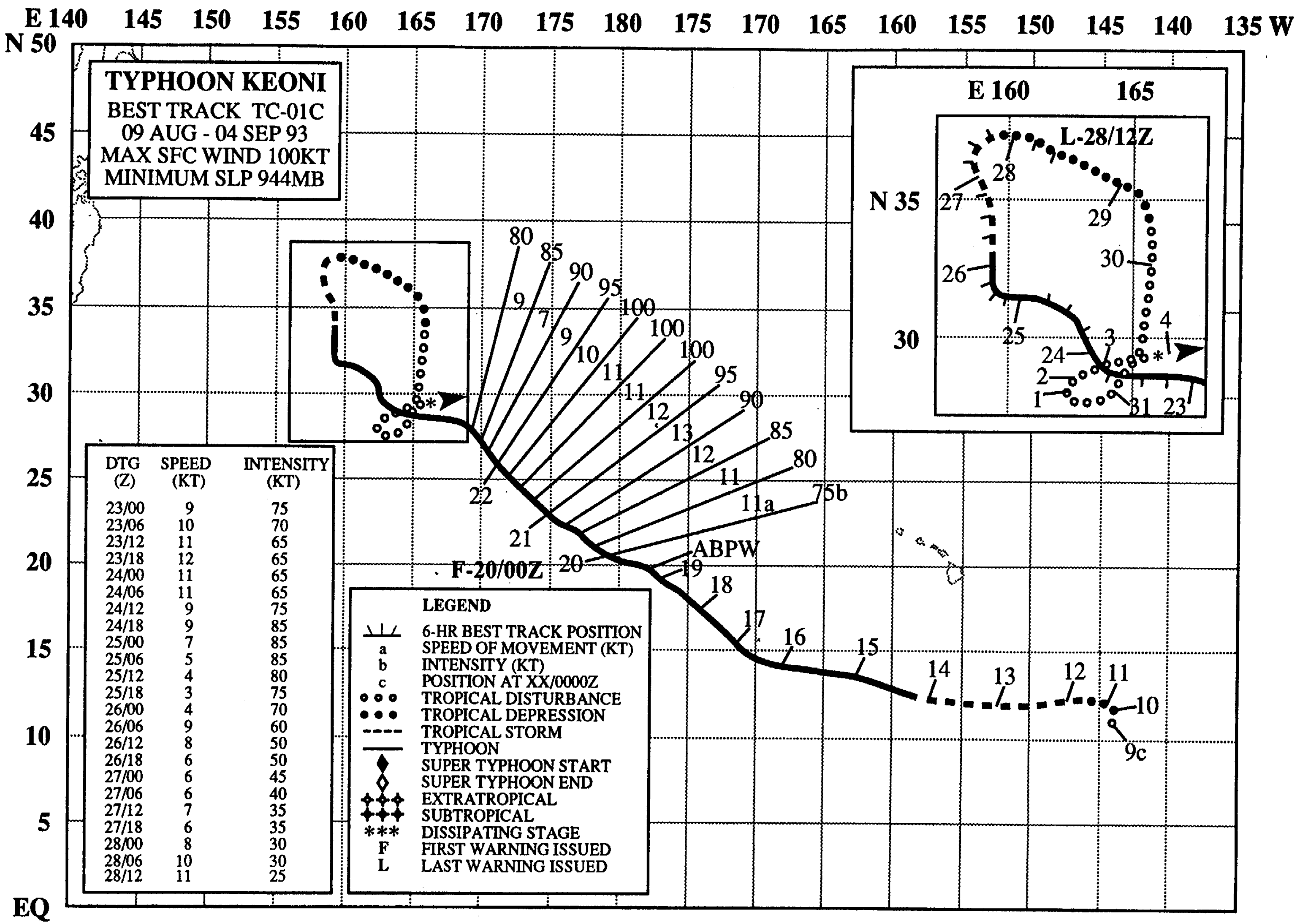
311800Z - Following the development of a well developed banding eye feature and a satellite intensity estimate of 65 kt (33 m/sec), Yancy was upgraded to typhoon intensity.

September
020600Z - After a period of rapid intensification and a subsequent satellite intensity estimate of 127 kt (65 m/sec), Yancy was upgraded to super typhoon intensity.
041200Z - The final warning was issued as Yancy dissipated in the Sea of Japan.

III. IMPACT

Making landfall over southern Kyushu at approximately 030700Z, Yancy packed estimated maximum sustained winds of 115 kt (59 m/sec). Weather observations from Kanoya, Japan (WMO 47850), along coastal southern Kyushu, reported maximum gusts of 129 kt (66 m/sec). A total of 42 deaths (27 in Kagoshima Prefecture near the point of landfall), 155 injuries, and 5 missing people were attributed to Yancy as it traversed over Japan. More than 124 homes were destroyed, 4620 homes and businesses damaged, and 400,000 homes were without electricity. In addition, there was extensive agricultural damage and a widespread disruption of rail and airline travel in Southeastern Honshu.

Maximum winds at Kadena AB, Okinawa were reported at 48 kt with gusts to 77 kt (25G40 m/sec). Sasebo and Iwakuni reported weaker maximum sustained winds of 28 kt gusting to 56 kt (14G29 m/sec) and 30 kt gusting to 45 (15G23 m/sec), respectively.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
23/00	9	75
23/06	10	70
23/12	11	65
23/18	12	65
24/00	11	65
24/06	11	65
24/12	9	75
24/18	9	85
25/00	7	85
25/06	5	85
25/12	4	80
25/18	3	75
26/00	4	70
26/06	9	60
26/12	8	50
26/18	6	50
27/00	6	45
27/06	6	40
27/12	7	35
27/18	6	35
28/00	8	30
28/06	10	30
28/12	11	25

TYPHOON KEONI (01C)

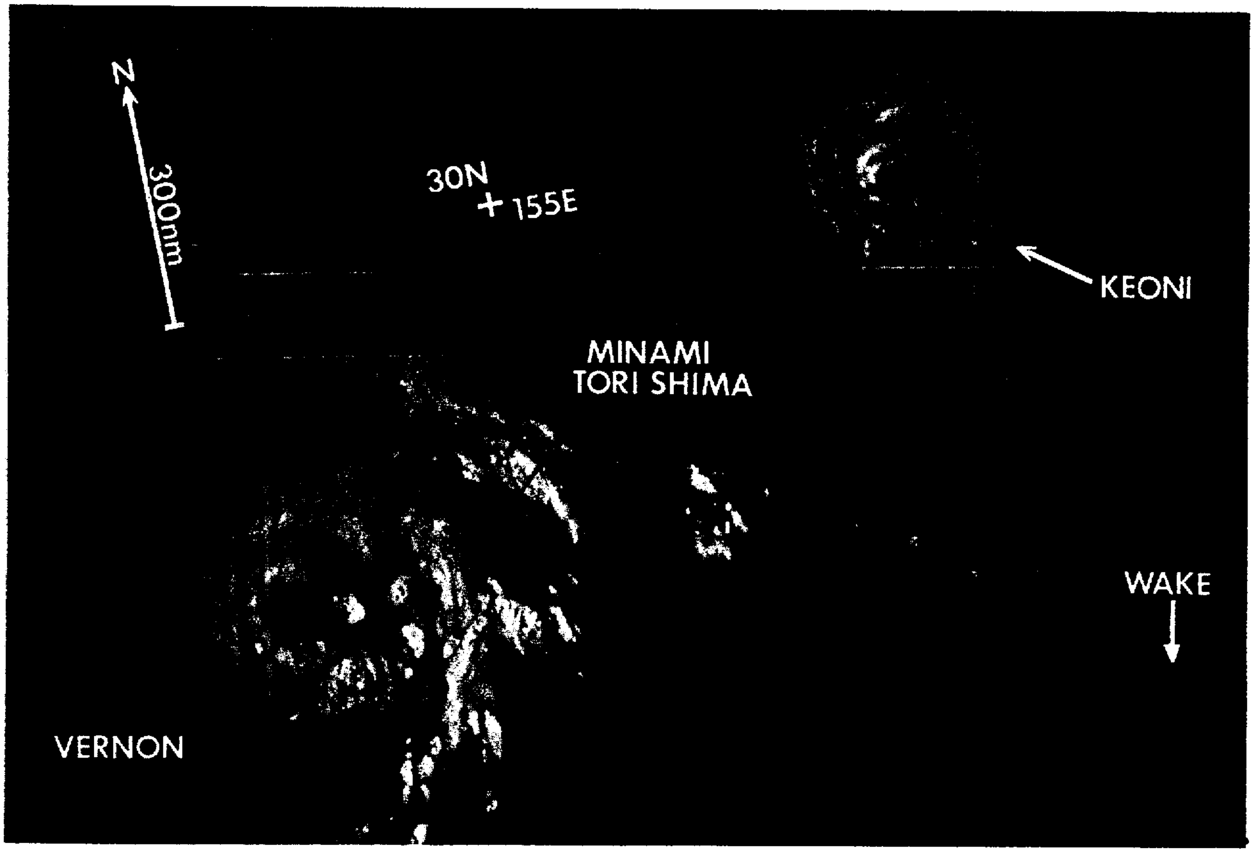


Figure 3-01C-1 Keoni tracks in tandem with Vernon (17W) (242313Z August visual NOAA imagery.)

I. HIGHLIGHTS

Typhoon Keoni formed southeast of Hawaii in the central Pacific and crossed into the JTWC area of responsibility on 20 August. Keoni remained over open water its entire life and did not pose a significant threat to land. Keoni tracked northwest in tandem with Typhoon Vernon (17W) before dissipating (Figure 3-01C-1) over cool water.

II. CHRONOLOGY OF EVENTS

August

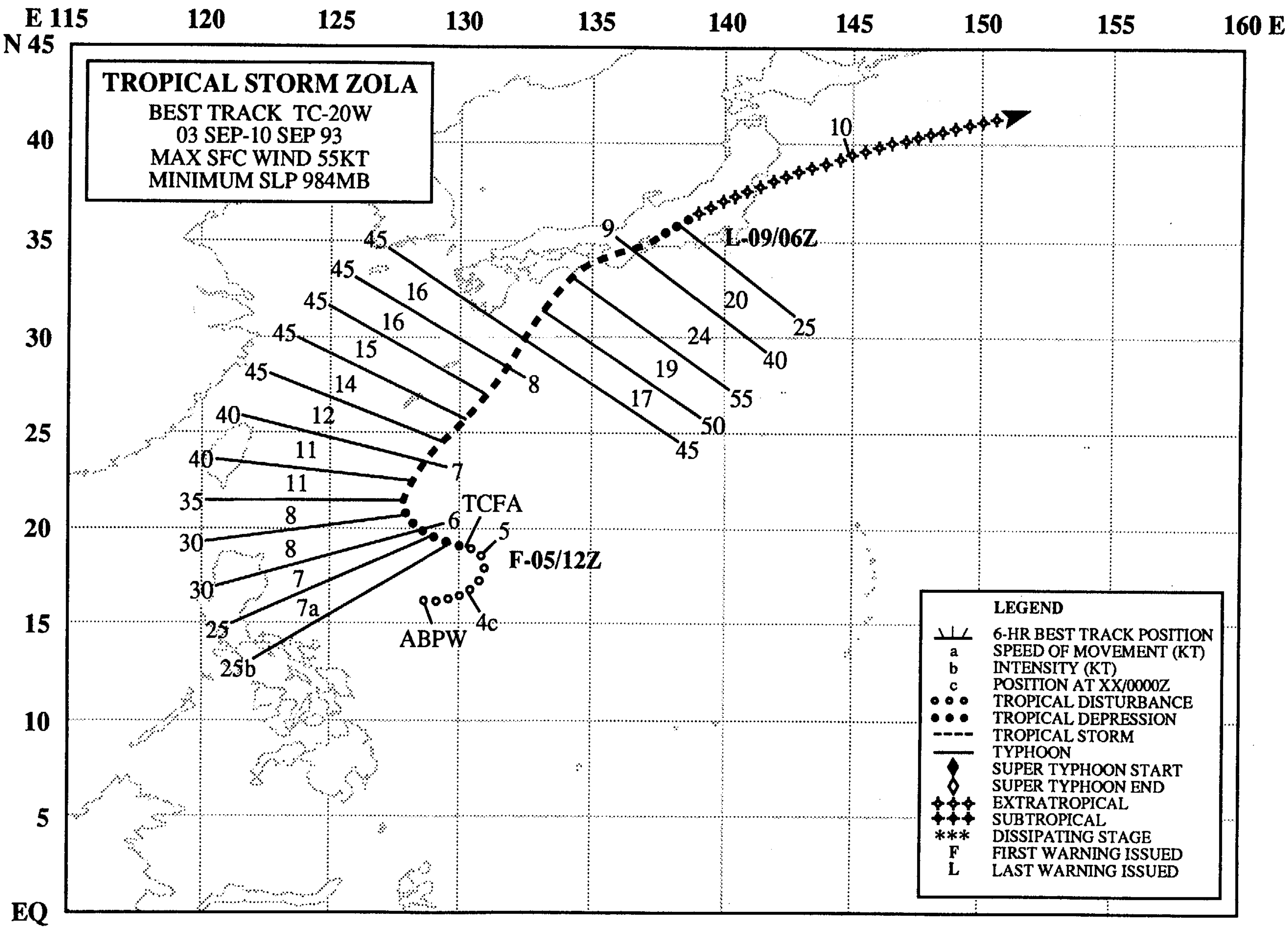
200000Z - The first warning on Typhoon Keoni is issued after the storm crossed the international date line into the JTWC area of responsibility.

210600Z - Keoni attained a maximum intensity of 100 kt (51 m/sec). Keoni earlier attained this maximum in the central Pacific.

281200Z - The final warning was issued on Keoni as it dissipated over cool water in an area of strong upper level vertical wind shear.

III. IMPACT

None.


TROPICAL STORM ZOLA
BEST TRACK TC-20W
03 SEP-10 SEP 93
MAX SFC WIND 55KT
MINIMUM SLP 984MB
E 115
120
125
130
135
140
145
150
155
160 E
N 45
40
35
30
25
20
15
10
5
EQ
TCFA
F-05/12Z
L-09/06Z
ABPW
4c
25b
7a
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TROPICAL STORM ZOLA (20W)

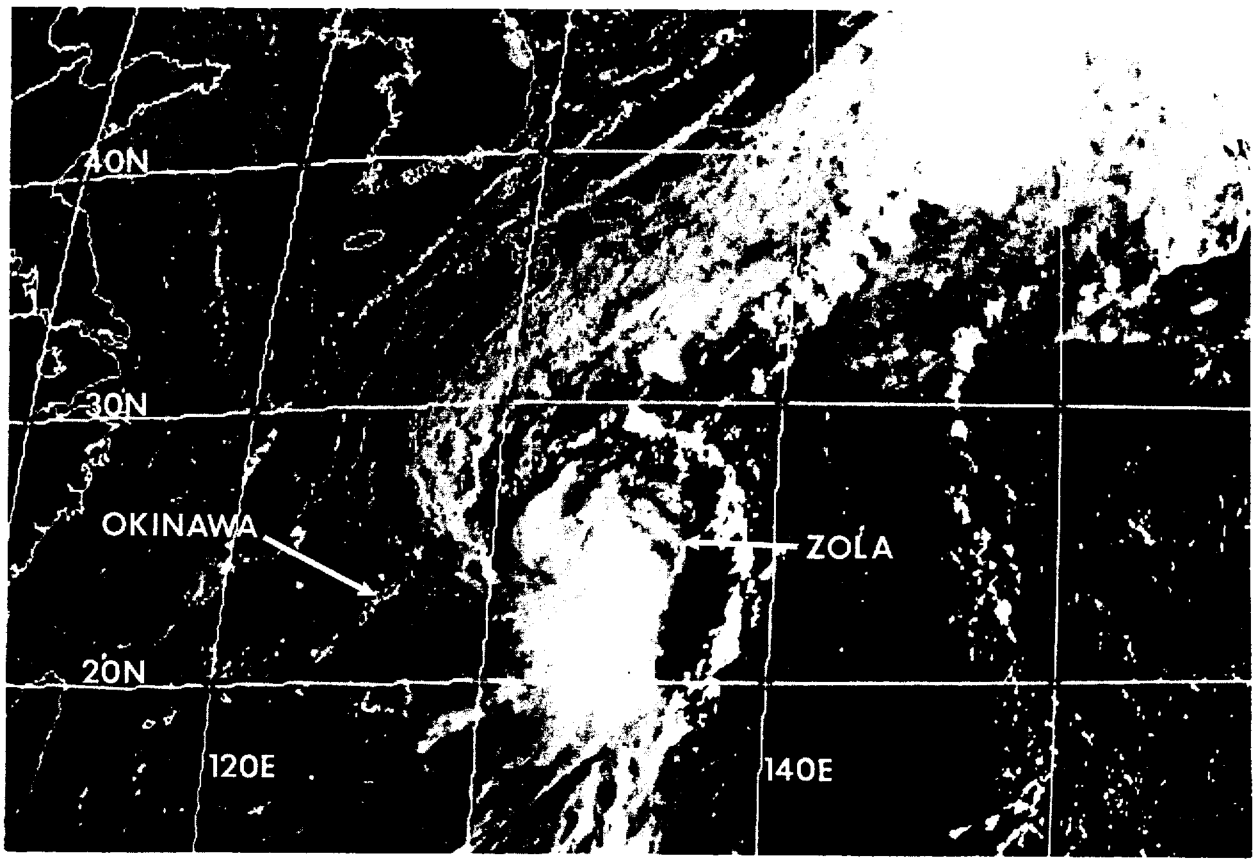


Figure 3-20-1 Zola at tropical storm intensity passes to the east of Okinawa (072230Z September visual GMS imagery).

I. HIGHLIGHTS

Forming within the monsoon trough in the Philippine Sea, Zola was the first of six significant tropical cyclones to occur during September. Steadily accelerating north-northeastward and passing east of Okinawa (Figure 3-20-1), Zola reached it's maximum intensity of 55 kt (28 m/sec) just prior to landfall in Japan.

II. CHRONOLOGY OF EVENTS

September

030600Z - An area of convection within the monsoon trough, east of Luzon, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

050800Z - Increased convective organization, southwest of a cyclonic cell in the Tropical Upper Tropospheric Trough (TUTT), led to the issuance of a Tropical Cyclone Formation Alert on the disturbance.

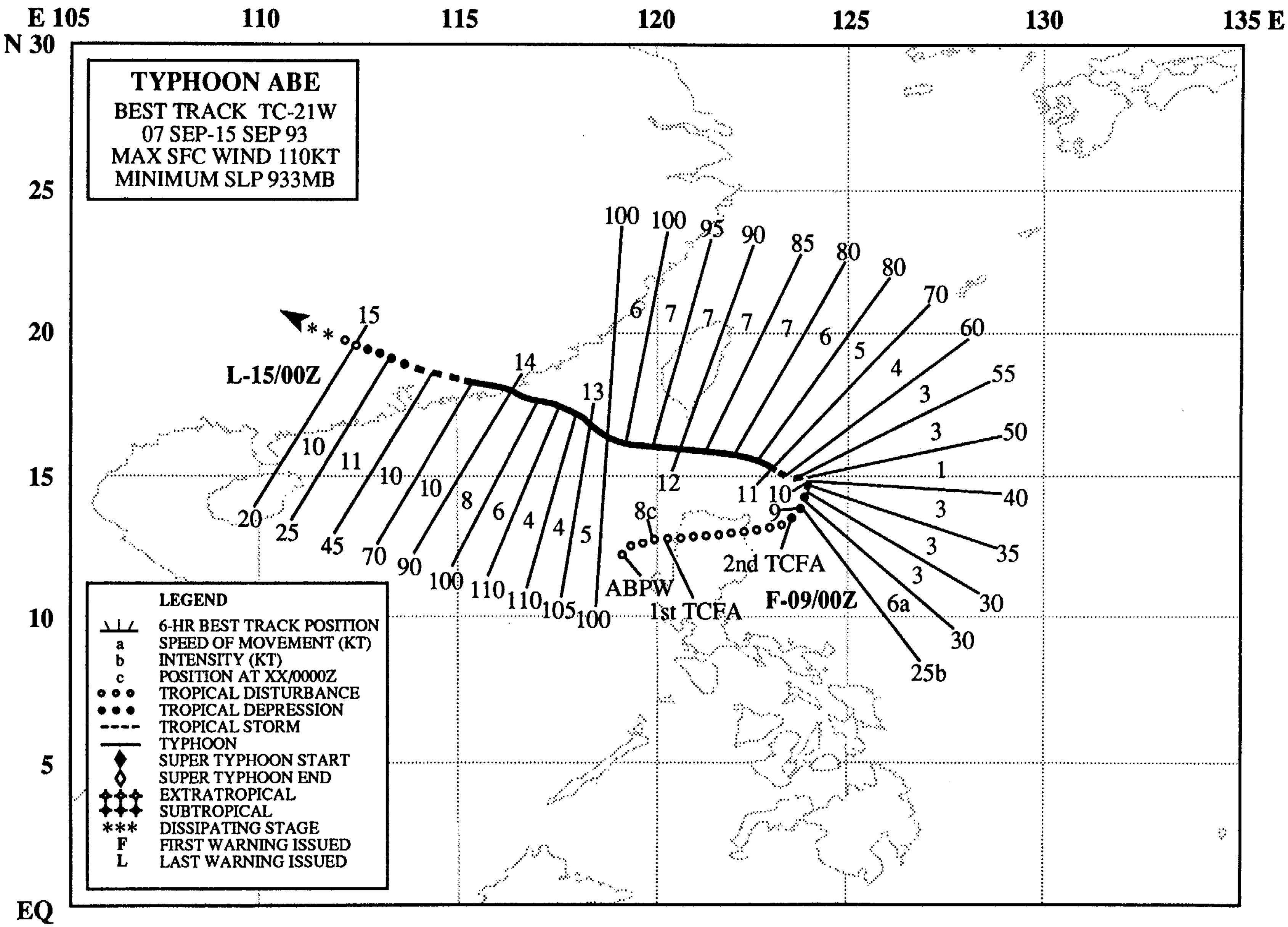
051200Z - The first warning was issued based on improved convective curvature and a satellite intensity estimate of 25 kt (13 m/sec).

061200Z - Based on a satellite intensity estimate of 35 kt (18 m/sec), Zola was upgraded to tropical storm intensity.

090600Z - The final warning was issued as Zola transitioned into an extratropical low over Honshu, Japan.

III. IMPACT

Press reports indicated that heavy rains associated with Zola flooded homes, caused landslides, and stopped train service in Wakayama, a Japanese prefecture 280 nm (520 km) southwest of Tokyo.


TYPHOON ABE
BEST TRACK TC-21W
07 SEP-15 SEP 93
MAX SFC WIND 110KT
MINIMUM SLP 933MB
E 105
110
115
120
125
130
135 E
N 30
25
20
15
10
5
EQ
L-15/00Z
F-09/00Z
ABPW
1st TCFA
2nd TCFA
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED

TYPHOON ABE (21W)

I. HIGHLIGHTS

The first typhoon of September, Abe, initially took an unusual eastward track across Luzon, in the wake of Tropical Storm Zola (20W). After entering the Philippine Sea, Abe slowly turned back to the west, passed north of Luzon, and intensified to 110 kt (57 m/sec) before making landfall in China, east of Hong Kong. Radar images from Kaohsiung (WMO 46744) revealed a dramatic decrease in the diameter of the eye over a period of 20 hours (Figure 3-21-1) as Abe passed just to the south of Taiwan.

II. CHRONOLOGY OF EVENTS

September

070600Z - An area of persistent convection within the monsoon trough, west of Luzon, resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

080300Z - A Tropical Cyclone Formation Alert (TCFA) was issued on the disturbance in the South China Sea, following a period of rapid development in its convective organization.

082100Z - A second TCFA was issued after the disturbance crossed Luzon and reorganized in the Philippine Sea.

090000Z - The first warning was issued on the tropical depression following an improvement in convective curvature and a satellite intensity estimate of 25 kt (13 m/sec).

091800Z - Based on continuously increasing convective organization and a satellite intensity estimate of 35 kt (18 m/sec), Abe was upgraded to a tropical storm.

110000Z - Following the development of a cloud filled eye and a satellite intensity estimate of 77 kt (40 m/sec), Abe was upgraded to typhoon intensity.

150000Z - The final warning was issued on Abe as it dissipated in southern China.

III. IMPACT

No reports received.

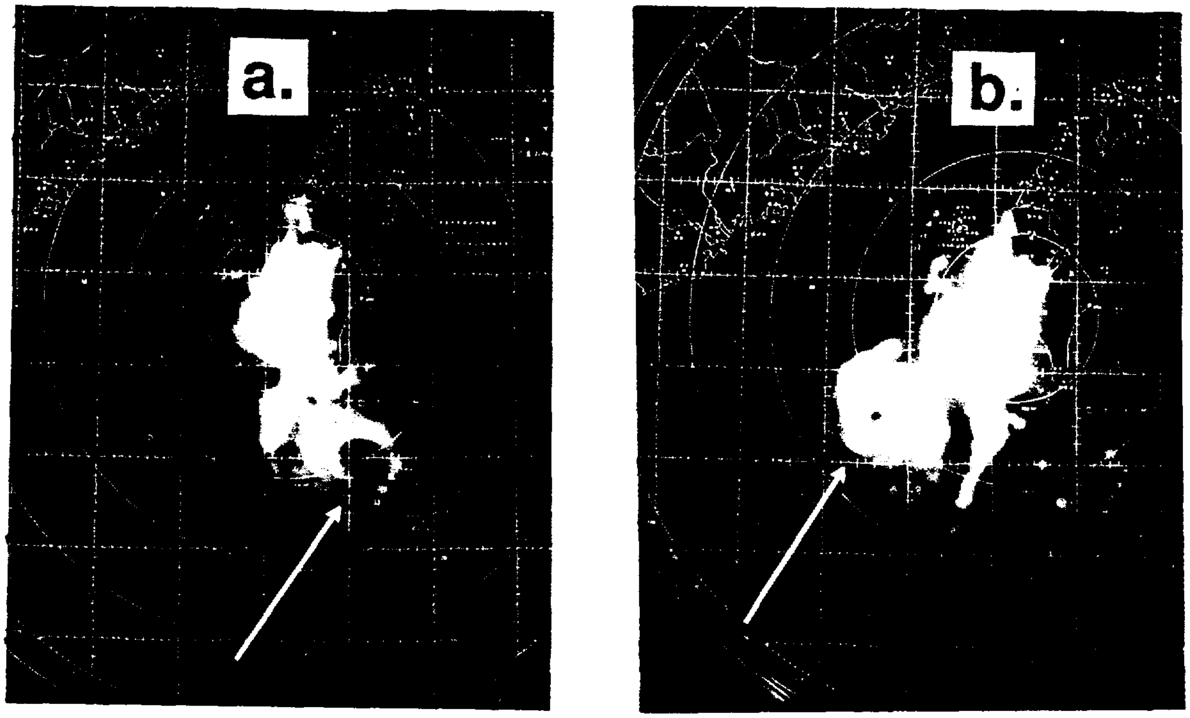
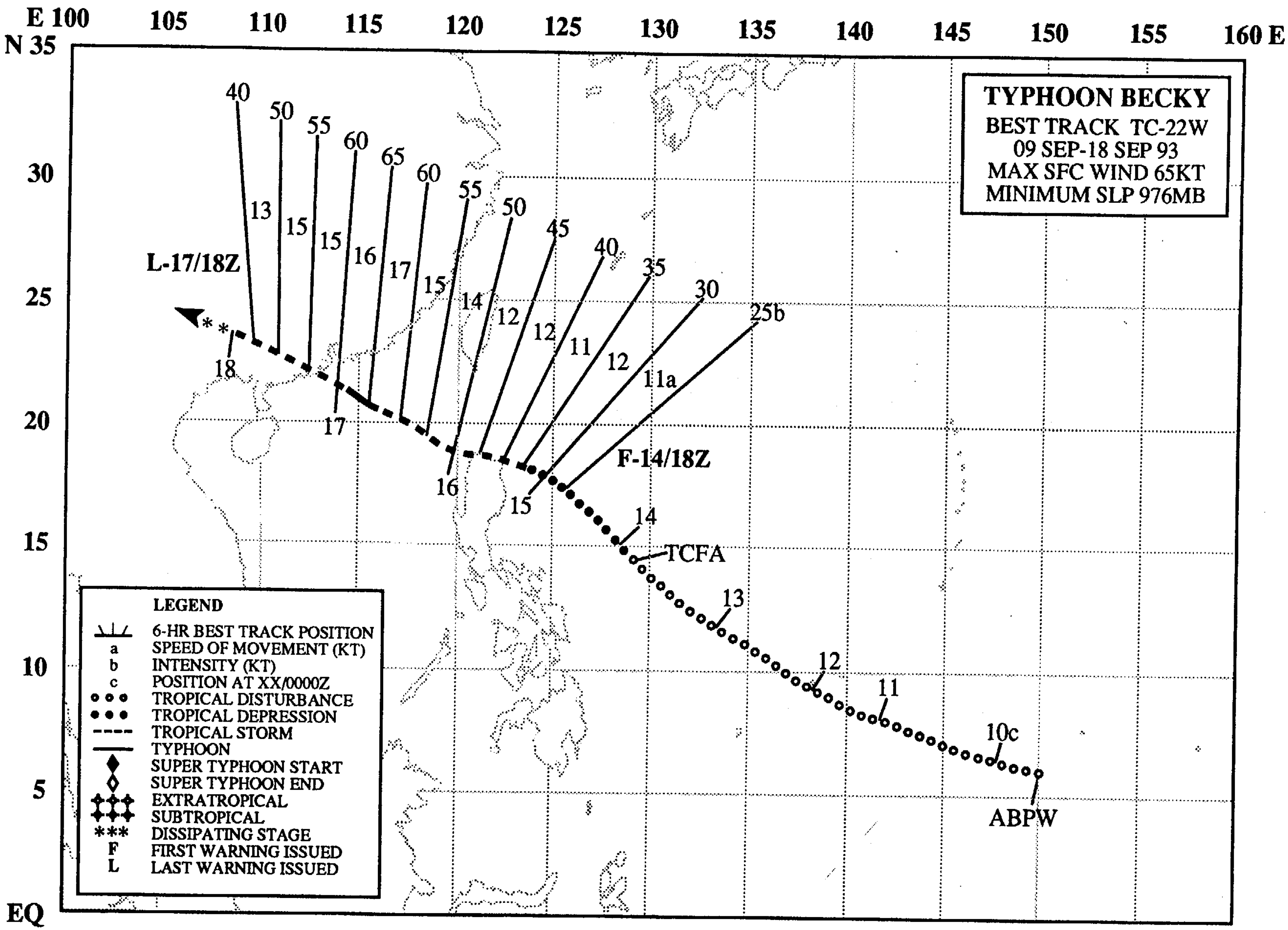


Figure 3-21-1 Radar images from Kaohsiung (WMO 46744): a) at 112200Z, and b) 121800Z September show the dramatic decrease in Abe's eye diameter from 25 to 8 nm (45 to 15 km) as intensification takes place (Radar photos courtesy of the Central Weather Bureau, Taipei, Taiwan).



TYPHOON BECKY
BEST TRACK TC-22W
09 SEP-18 SEP 93
MAX SFC WIND 65KT
MINIMUM SLP 976MB
L-17/18Z
F-14/18Z
TCFA
ABPW
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145
150
155
160 E
N 35
30
25
20
15
10
5
EQ

TYPHOON BECKY (22W)

I. HIGHLIGHTS

The third of six significant tropical cyclones to form during September, Becky remained a weak cyclonic disturbance while tracking towards northern Luzon. After the first warning was issued, Becky intensified at a faster than average rate and attained typhoon intensity 48 hours later. The tropical cyclone reached a peak intensity of 65 kt (33 m/sec) ten hours prior to landfall in southern China. Becky (Figure 3-22-1) was the second typhoon in three days to threaten Hong Kong.

II. CHRONOLOGY OF EVENTS

September

091800Z - An area of persistent convection within the monsoon trough, near the Caroline Islands, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

132000Z - A Tropical Cyclone Formation Alert was issued as a result of increased convection and convective curvature.

141800Z - The first warning was issued based on a satellite intensity estimate of 25 kt (13 m/sec).

150600Z - Based on satellite intensity estimates of 35 kt (18 m/sec), Becky was upgraded to a tropical storm, as it approached Luzon.

161800Z -With the development of a 13 nm (24 km) cloud-filled eye and a satellite intensity estimate of 65 kt (33 m/sec), Becky was briefly upgraded to typhoon intensity.

171800Z - The final warning was issued on Becky as it dissipated over southern China, southwest of Hong Kong.

III. IMPACT

Seven deaths and 60 people reported missing near Hong Kong were attributed to the passage of Becky.

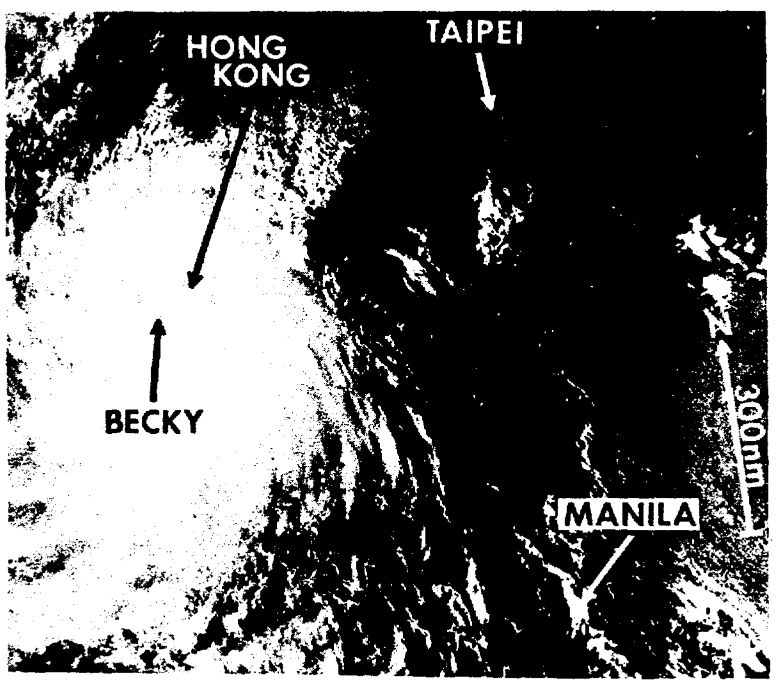
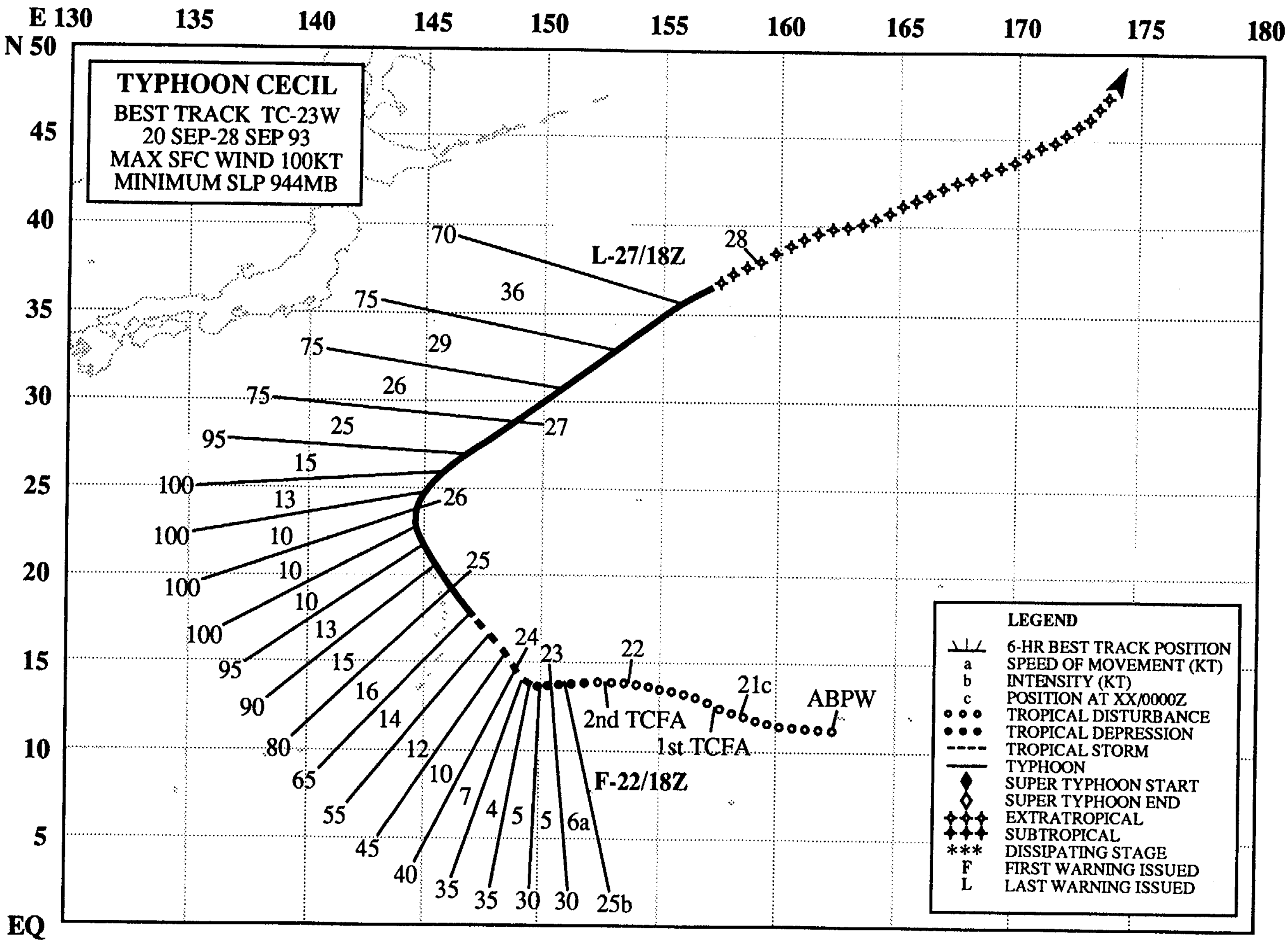


Figure 3-22-1 Typhoon Becky with a closed cloud filled eye makes land fall to the west of Hong Kong (170139Z September visual DMSP imagery.)



TYPHOON CECIL
BEST TRACK TC-23W
20 SEP-28 SEP 93
MAX SFC WIND 100KT
MINIMUM SLP 944MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-27/18Z
F-22/18Z
2nd TCFA
1st TCFA
ABPW

TYPHOON CECIL (23W)

I. HIGHLIGHTS

The fourth significant tropical cyclone to develop during September, Cecil, briefly threatened the Mariana Islands before turning to the northwest and ultimately recurving away from any populated areas.

II. CHRONOLOGY OF EVENTS

September

200600Z - An area of persistent convection within an extended monsoon trough west of Kwajalein in the Marshall Islands resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

210600Z - A Tropical Cyclone Formation Alert (TCFA) was issued based on an increase in convection and convective curvature.

220530Z - A further consolidation of convection near the circulation center and a westerly wind burst led to the issuance of a second TCFA.

221800Z - The first warning was issued based on a satellite intensity estimate of 25 kt (13 m/sec) while the depression was located east of Guam.

230000Z - As a result of continued development of convective curvature and a satellite intensity estimate of 35 kt (18 m/sec), Cecil was upgraded to tropical storm intensity. Post-storm analysis indicated that Cecil actually reached tropical storm intensity about twelve hours later.

241800Z - In response to a satellite intensity estimate of 65 kt (33 m/sec), Cecil was upgraded to typhoon intensity.

271800Z - The final warning was issued on Cecil as it transitioned into an extratropical low.

III. IMPACT

Convection associated with a monsoon surge flowing into Cecil brought badly needed rainfall to Guam as the water level in Guam's Fena Reservoir rose nearly 10 feet (3 m) (Figure 3-23-1).

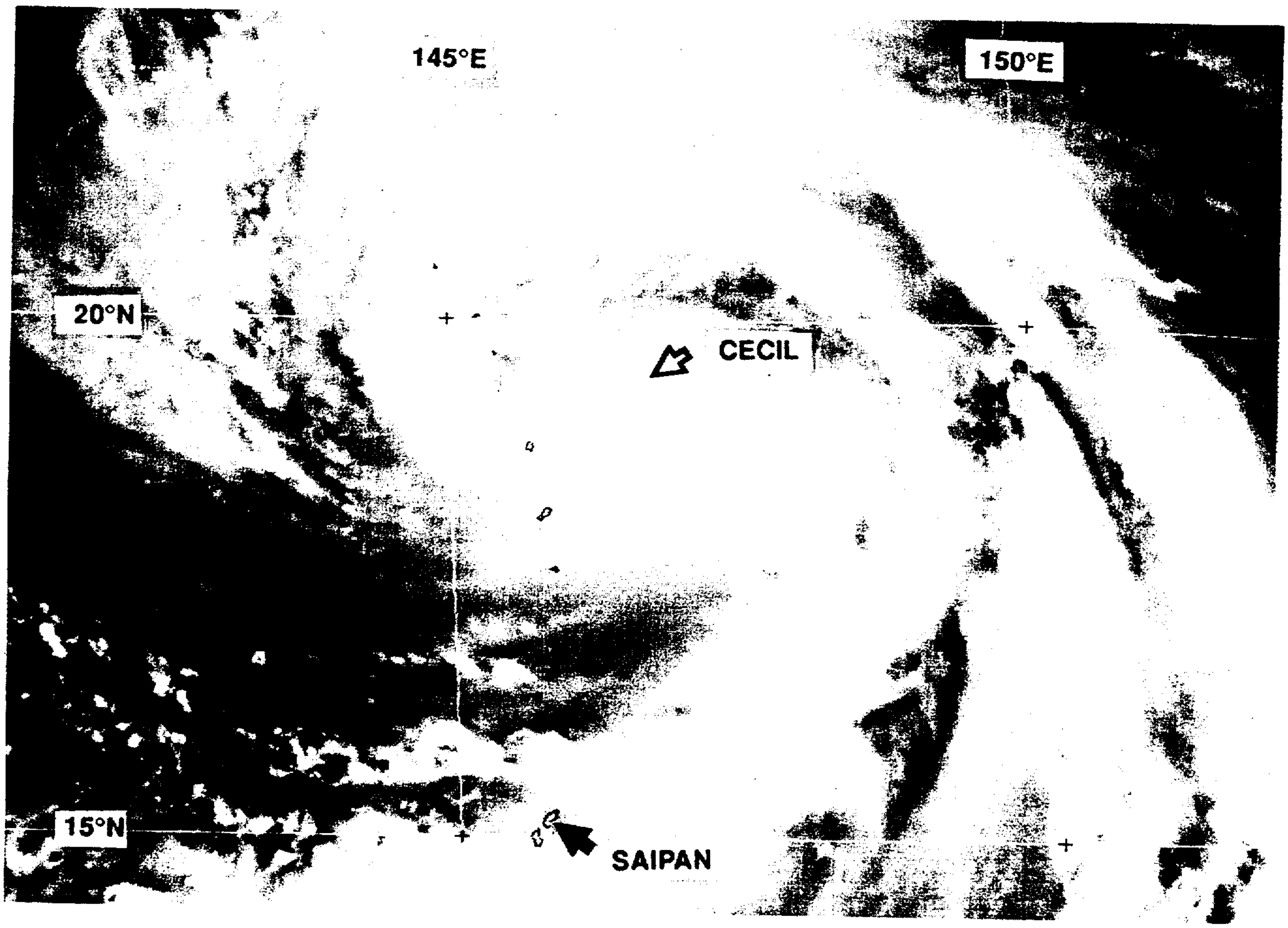
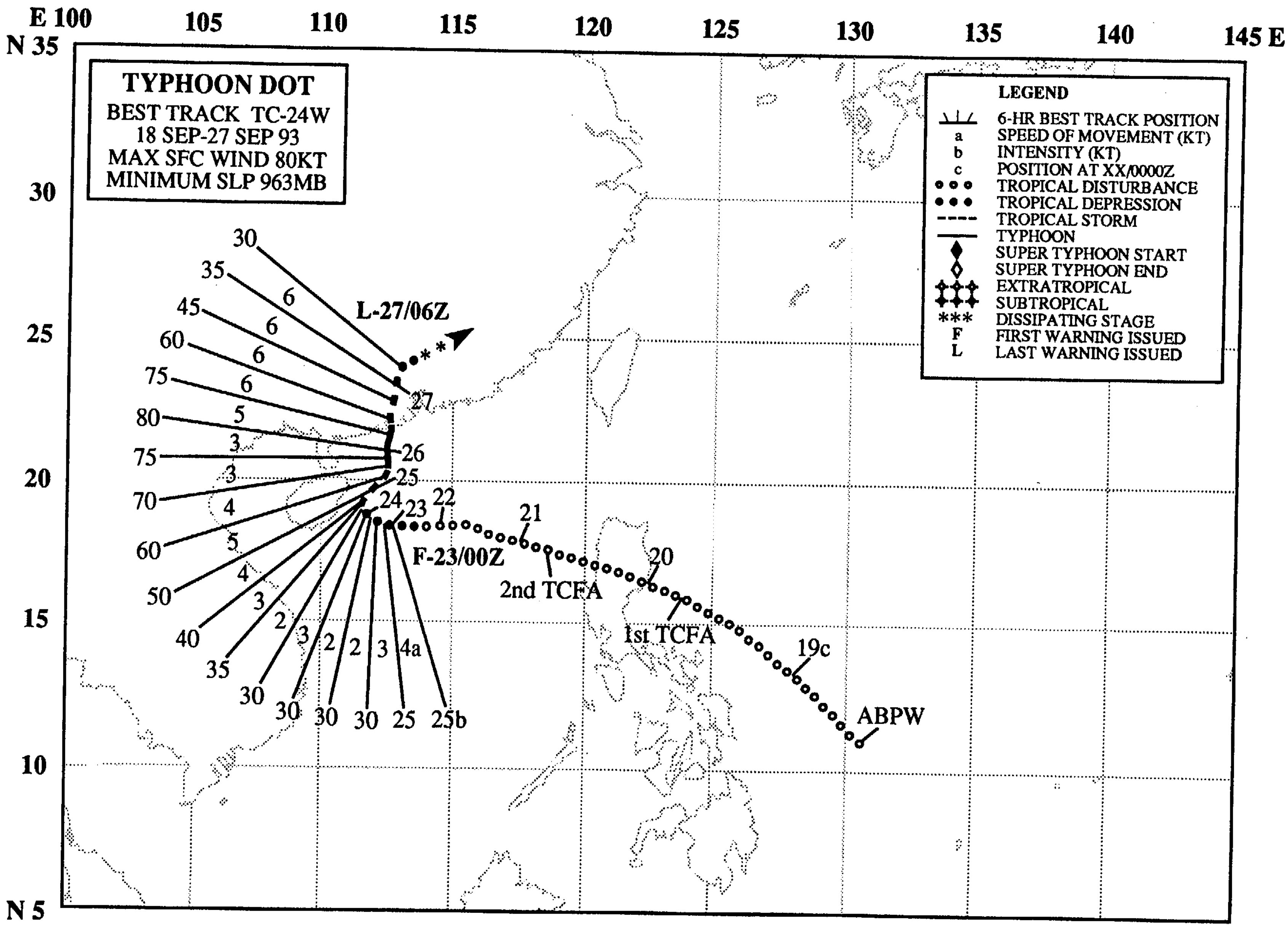


Figure 3-23-1 Although the cloud-filled eye of Typhoon Cecil is located 250 nm (465 km) to the north of Saipan, bands of deep convection are bringing heavy rains to the southern islands of the Marianas (242331Z September visual GMS imagery).


TYPHOON DOT
BEST TRACK TC-24W
18 SEP-27 SEP 93
MAX SFC WIND 80KT
MINIMUM SLP 963MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145 E
N 35
30
25
20
15
10
N 5
L-27/06Z
F-23/00Z
2nd TCFA
1st TCFA
ABPW
19c
20
21
22
23
24
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26
27

TYPHOON DOT (24W)

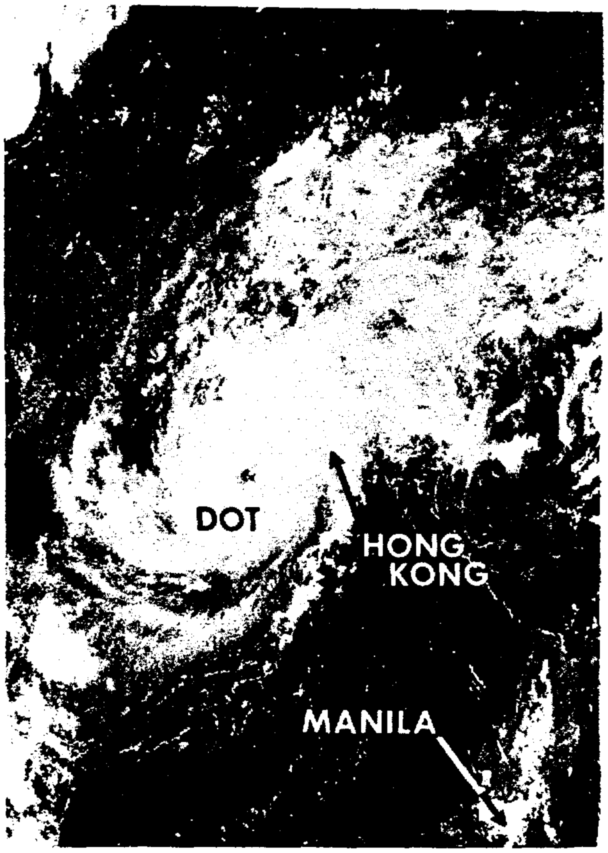


Figure 3-24-1 The eye of Dot, which is located southwest of Hong Kong, is visible in the moonlight. The city lights of Hanoi and Manila can also be seen (251321Z September nighttime visual DMSP imagery).

I. HIGHLIGHTS

Initially forming in the Philippine Sea, Dot slowly consolidated as it moved swiftly across Luzon. In the South China Sea, weak steering flow allowed Dot to slow to about 2 kt (1 m/sec), and intensify from a tropical depression to a typhoon. Moving erratically to the north, Dot eventually made landfall over southern China, near Hong Kong (Figure 3-24-1).

II. CHRONOLOGY OF EVENTS

September

180600Z - An area of persistent convection within the monsoon trough, north of Palau, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

191900Z - A Tropical Cyclone Formation Alert (TCFA) was issued following an increase in convection near the circulation center.

201900Z - A second TCFA was issued after the disturbance crossed Luzon with it's convective organization weakened but intact.

211900Z - The second TCFA was canceled due to decreased convective organization.

230000Z - The first warning was issued, without a TCFA in effect, based upon a synoptic report of 25 kt (13 m/sec) near the circulation center.

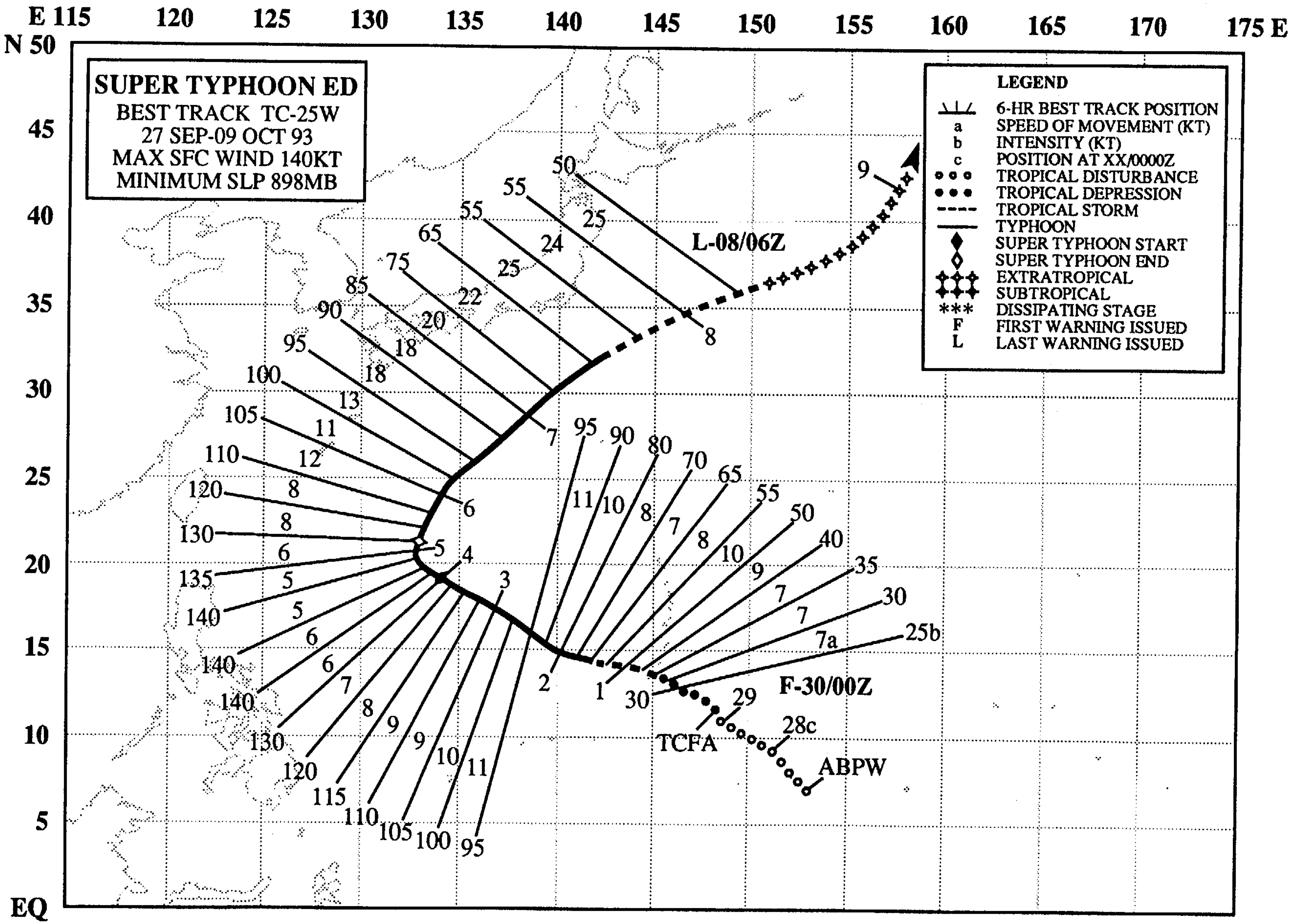
241200Z- Based upon improved convective organization and a satellite intensity estimate of 35 kt (18 m/sec), Dot was upgraded to tropical storm intensity.

250600Z - Following the development of a 25 nm (46 km) cloud filled banding-type eye and a satellite intensity estimate of 65 kt (33 m/sec), Dot was upgraded to typhoon intensity.

270600Z - The final warning was issued on Dot as it dissipated in southern China.

III. IMPACT

News reports stated that seven people were rescued and one person was still missing one day after Dot sunk their fishing vessel near Hong Kong. In addition, with the exception of the international airport, all public transportation in Hong Kong was either curtailed or suspended.


SUPER TYPHOON ED
BEST TRACK TC-25W
27 SEP-09 OCT 93
MAX SFC WIND 140KT
MINIMUM SLP 898MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
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175 E
N 50
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5
EQ
L-08/06Z
F-30/00Z
TCFA
ABPW
28c
25b
7a

SUPER TYPHOON ED (25W)

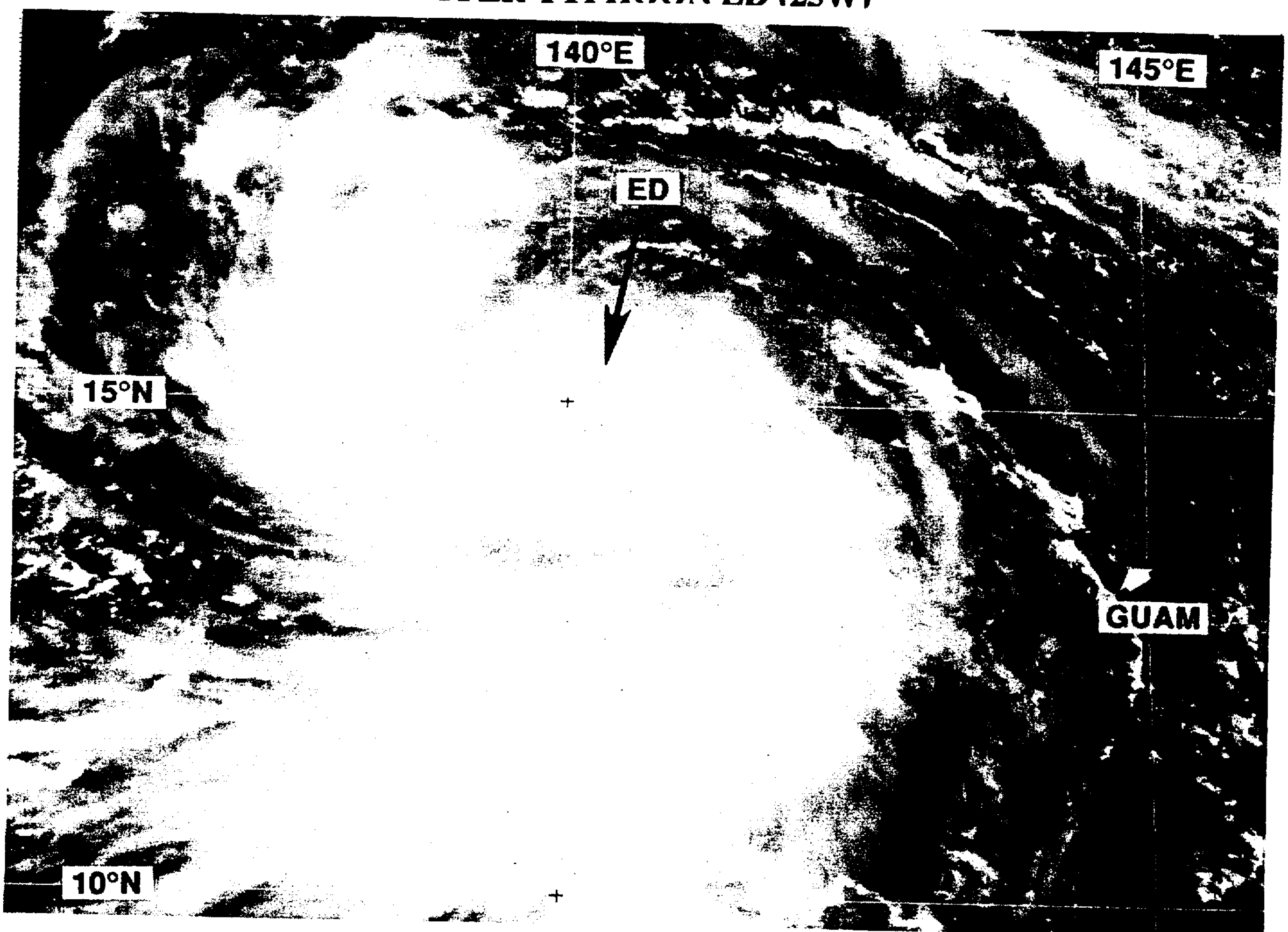


Figure 3-25-1 On the satellite imagery, a small eye becomes visible shortly after Ed reaches typhoon intensity (020031Z October visual GMS imagery).

I. HIGHLIGHTS

The second tropical cyclone to threaten the Mariana Islands within a week, Ed, passed directly over the NEXRAD Doppler weather radar on Guam. Initially forming in the Caroline Islands, Ed steadily developed from a tropical depression to super typhoon intensity within five days. During its intensification from a typhoon to a super typhoon, Ed possessed a small eye (Figure 3-25-1). During most of Ed's lifetime, it underwent binary interaction with Typhoon Flo (26W).

II. CHRONOLOGY OF EVENTS

September

270600Z - An area of persistent convection within the monsoon trough near Chuuk, in the eastern Caroline Islands, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

290600Z - A Tropical Cyclone Formation Alert was issued following an increase in convection near an exposed low-level circulation center.

300000Z - The first warning was issued based upon increased convective curvature and a satellite intensity estimate of 25 kt (13 m/sec).

301800Z - Based upon a satellite intensity estimate of 45 kt (23 m/sec), Ed was upgraded to a tropical storm.
October
011200Z - The appearance of a warm spot in the cold CDO and the resulting satellite intensity estimate of 65 kt (33 m/sec) prompted JTWC to upgrade Ed to a typhoon.
040000Z - A small eye deeply embedded in the CDO and a satellite intensity estimate of 127 kt (65 m/sec) led JTWC to upgrade Ed to a super typhoon.
080600Z - The final warning was issued on Ed as it transitioned into an extratropical low well to the east of Japan.

III. IMPACT

Ed brought badly needed heavy rainfall to Guam which resulted in some localized flooding on the island. A peak gust of 53 kt (27 m/sec) was reported at Andersen AFB as the tropical storm passed directly over Guam.

IV. DISCUSSION

a) NEXRAD — The passage of Ed's center over northern Guam, just after it had intensified to a tropical storm, resulted in the first-ever direct passage of a tropical cyclone over a NEXRAD Doppler weather radar. Guam's NEXRAD played a key role in short-term local forecasts as Ed approached the island. About 12 hours prior to landfall on Guam, the velocity dipole, or couplet, associated with the tightly curved wind flow around the small central calm area, became evident on the radial velocity product (RVP) generated by the NEXRAD. Three hours prior to landfall, it became evident from the NEXRAD fixes that Ed's center would pass directly over northern Guam. The RVP showed a small area of gales with an embedded peak velocity of 50 kt (26 m/sec) moving steadily towards the north end of Guam (Figure 3-25-2). Forecasters at Andersen Air Force Base, used this information to give what would turn out to be a very accurate short-range forecast of a brief period of gales with maximum gusts to 50 kt (26 m/sec). Andersen experienced gale-force sustained winds for about a half an hour (from 301230Z to 301300Z September) (Figure 3-25-2d). Wind gusts to 50 kt (26 m/sec) occurred for 10 minutes (1240Z to 1250Z) with a peak gust to 53 kt (27 m/sec) at 1242Z. The light wind core of Ed, during its passage over Guam, is herein referred to as an "eye"; the quotation marks indicating that it did not have an eye in the conventional sense of a central core — free of deep cloud — encircled at least 50% by a wall of tall cumulonimbus cloud. Abruptly, at 1300Z, the winds dropped to 10-15 kt (5-8 m/sec) as the "eye" of Ed passed just to the south of Andersen. These light winds lasted for about 15 minutes as the wind direction veered quickly from 030 degrees to 140 degrees. After the "eye" passage at Andersen, the wind speed increased to 25-30 kt (13-15 m/sec) with gusts to 35 kt (18 m/sec).

The structure of Ed as it passed over Guam, as revealed by the NEXRAD and from eyewitness reports, was very similar to that of a mature tropical cyclone — even though Ed had only just achieved minimal tropical storm intensity. It had a very small "eye" as revealed by the reflectivity pattern (see cover illustration), and its highest winds were packed very tightly along the northern periphery of the "eye". Also, the satellite image at this time showed that Ed possessed a curved band type cloud structure; which, using the Dvorak satellite intensity technique yielded 35 kt (18 m/sec). Nevertheless, the radar reflectivity, the radar Doppler velocity, and the recorded wind and pressure during Ed's passage over Guam all revealed a structure very much like that of a mature tropical cyclone.

The NEXRAD can process its reflectivity data through an algorithm to estimate rainfall rates, which are presented as 1-hour, 3-hour or storm total precipitation products. NEXRAD estimates of storm total

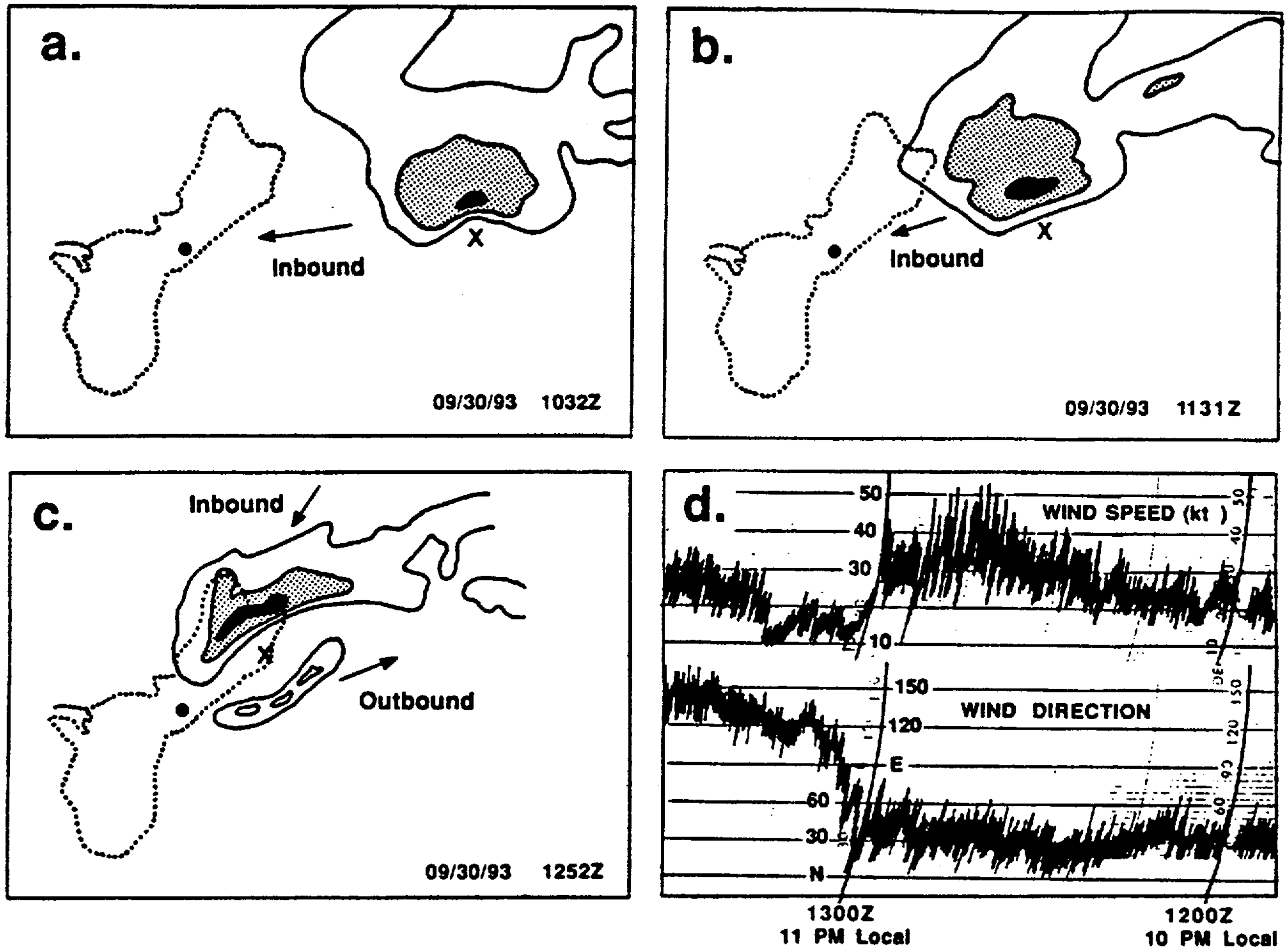


Figure 3-25-2 Radial velocities detected by the NEXRAD Doppler radar as Ed approached Guam: a) Illustration of the radial velocity display for 301032Z, b) 301131Z, c) 301252Z September, and d) the anemometer chart from Andersen AFB (WMO 91218) during the period (301200Z - 301300Z) which includes the gales preceding Ed's landfall. In panels a), b) and c), the outer contour encloses values ≥ 26 kt (13 m/sec), shaded area ≥ 36 kt (19 m/sec), and black areas indicate ≥ 50 kt (26 m/sec). The black dot locates the NEXRAD. Arrows indicate radial velocities as inbound or outbound with respect to the radar. Ed's circulation center is indicated by the x.

precipitation during Ed's passage over Guam (Figure 3-25-3a) were about 50% less than the rainfall actually measured by rain gauges on Guam (Figure 3-25-3b). The gradients of the NEXRAD integrated rainfall agreed with the relative magnitudes of the rainfall at the rain gauges: driest in the northeast of Guam and wettest on the west and southwest of Guam. The large observed error of total integrated rainfall may be due to the algorithm, developed for convective precipitation over the U.S. mainland, brief system outages, or an as yet unknown factor.

b) Binary interaction with Typhoon Flo (26W) — For most of Ed's lifetime it was in close proximity to Typhoon Flo. At their closest point of approach, Ed and Flo were separated by only 670 nm (1240 km) (Figure 3-25-4a and b); well within the 780 nm (1445 km) separation noted by Brand (1970) for cyclone binary interaction. The centroid-relative motion of Ed and Flo (Figure 3-25-4b) exhibited some of the features common to interacting tropical cyclones, see Lander and Holland (1993) (Figure 3-25-4c). For two days (300000Z September to 020000Z October), as both Ed and Flo moved steadily west-northwestward, they remained almost stationary with respect to the centroid-relative reference frame. At 021200Z, the two storms had begun a fairly steady cyclonic orbit and gradually closed to within 670 nm (1240 km) at 040000Z. Coincident with the start of the cyclonic orbit on the 2 October,

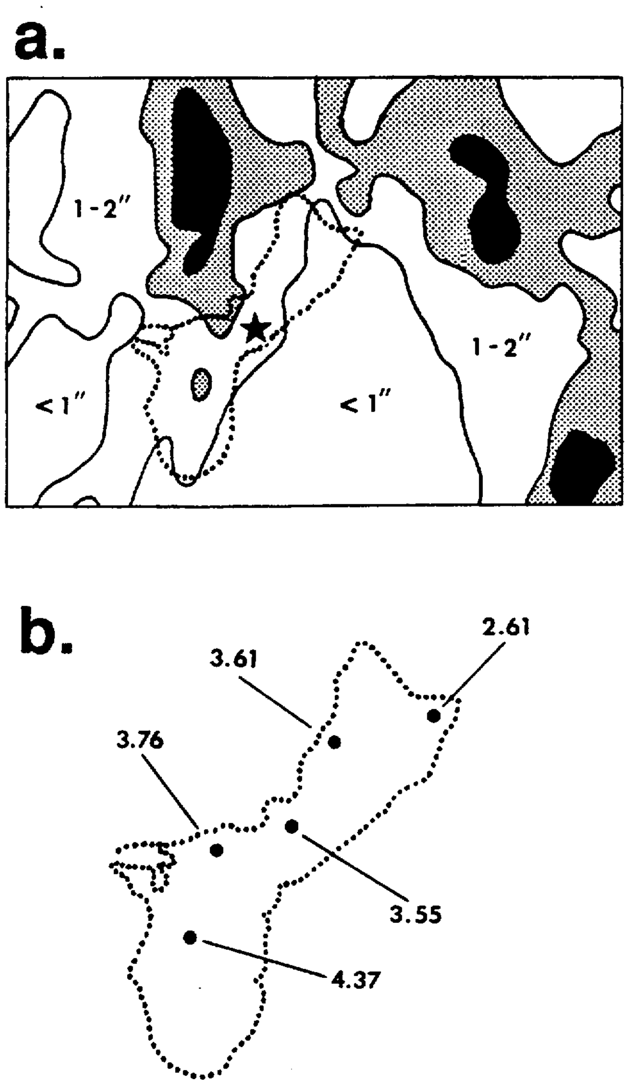


Figure 3-25-3 Total precipitation for Ed's passage over Guam: a) Storm total precipitation estimates from the NEXRAD for the period 282054Z September to 011504Z October. Shaded region = ≥ 2 inches (50 mm), black areas ≥ 3 inches (75 mm). Star locates the NEXRAD. (b) Storm total precipitation measurements from rain gauges for the same period.

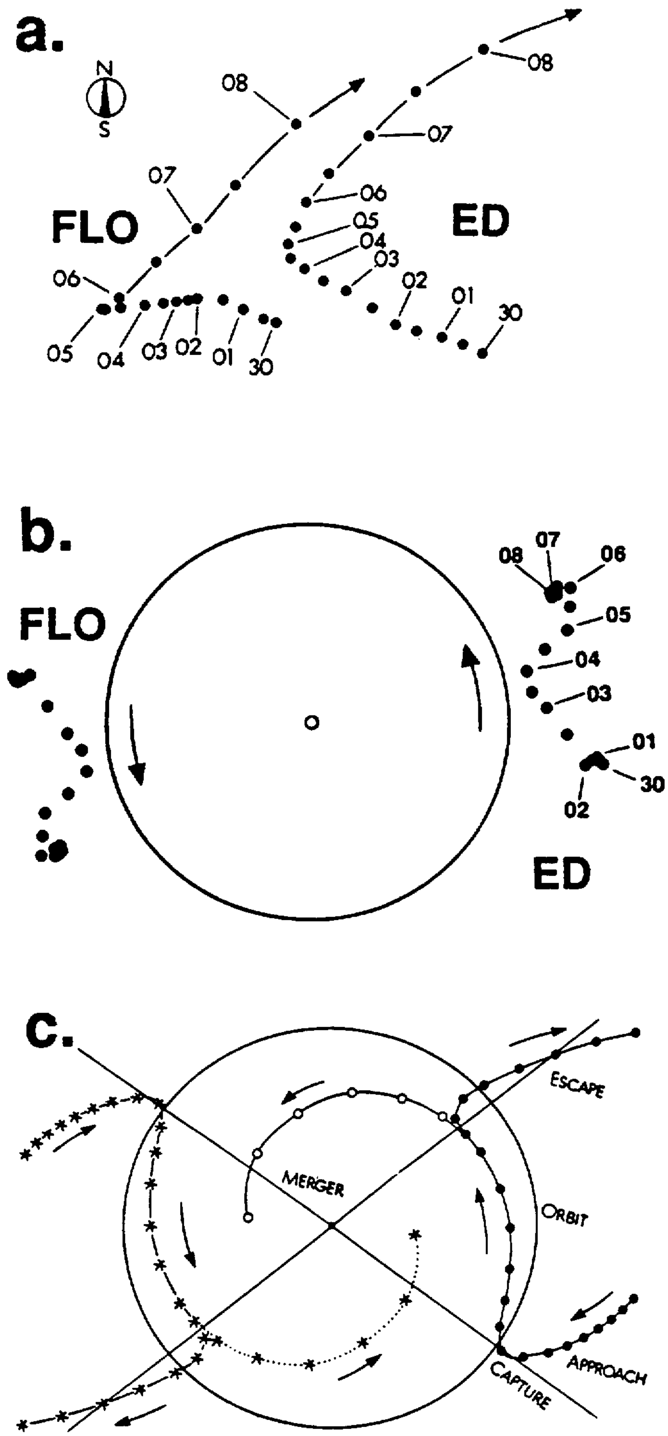
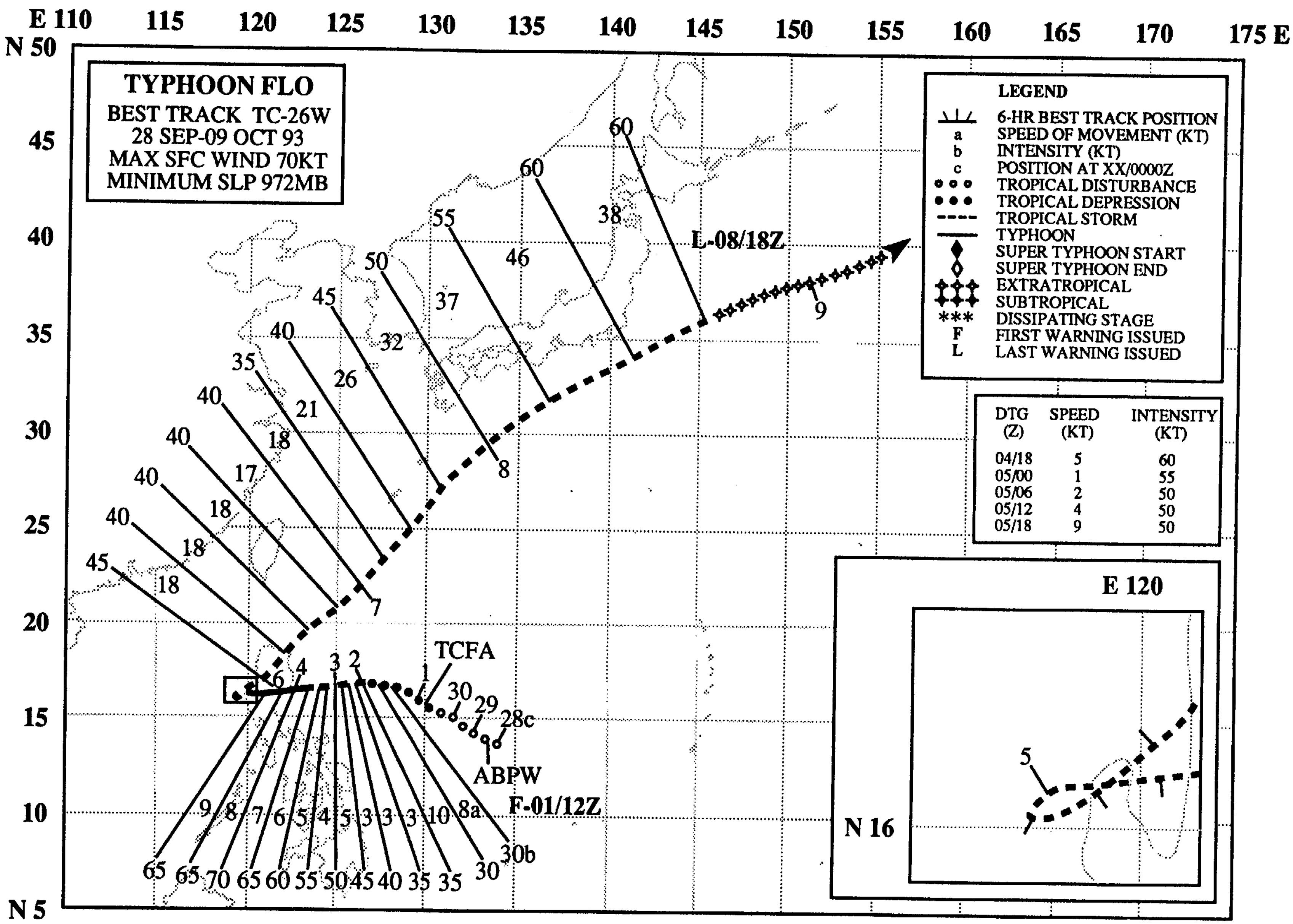


Figure 3-25-4 Binary interaction between Ed and Flo (26W): a) Tracks of Ed and Flo, b) Centroid-relative motion. Circle diameter = 600 nm (1110 km), dots = 12-hour time steps, and dates of 0000Z positions are indicated by 2-digit numbers. (c) Model of binary interaction between two tropical cyclones.

Ed turned a little more to the north and increased it's speed of motion, while Flo slowed its forward speed and turned to follow an unusual west-southwesterly track. The cyclonic orbit ended abruptly at 060000Z as Flo recurved and followed Ed into the midlatitudes on an accelerating northeasterly track. After recurvature, Ed and Flo remained almost stationary in the centroid-relative reference frame.


TYPHOON FLO
BEST TRACK TC-26W
28 SEP-09 OCT 93
MAX SFC WIND 70KT
MINIMUM SLP 972MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
DTG (Z) | SPEED (KT) | INTENSITY (KT)
04/18 | 5 | 60
05/00 | 1 | 55
05/06 | 2 | 50
05/12 | 4 | 50
05/18 | 9 | 50
TCFA
ABPW
F-01/12Z
L-08/18Z
E 120
N 16
E 110 115 120 125 130 135 140 145 150 155 160 165 170 175 E
N 50 45 40 35 30 25 20 15 10 N 5

TYPHOON FLO (26W)

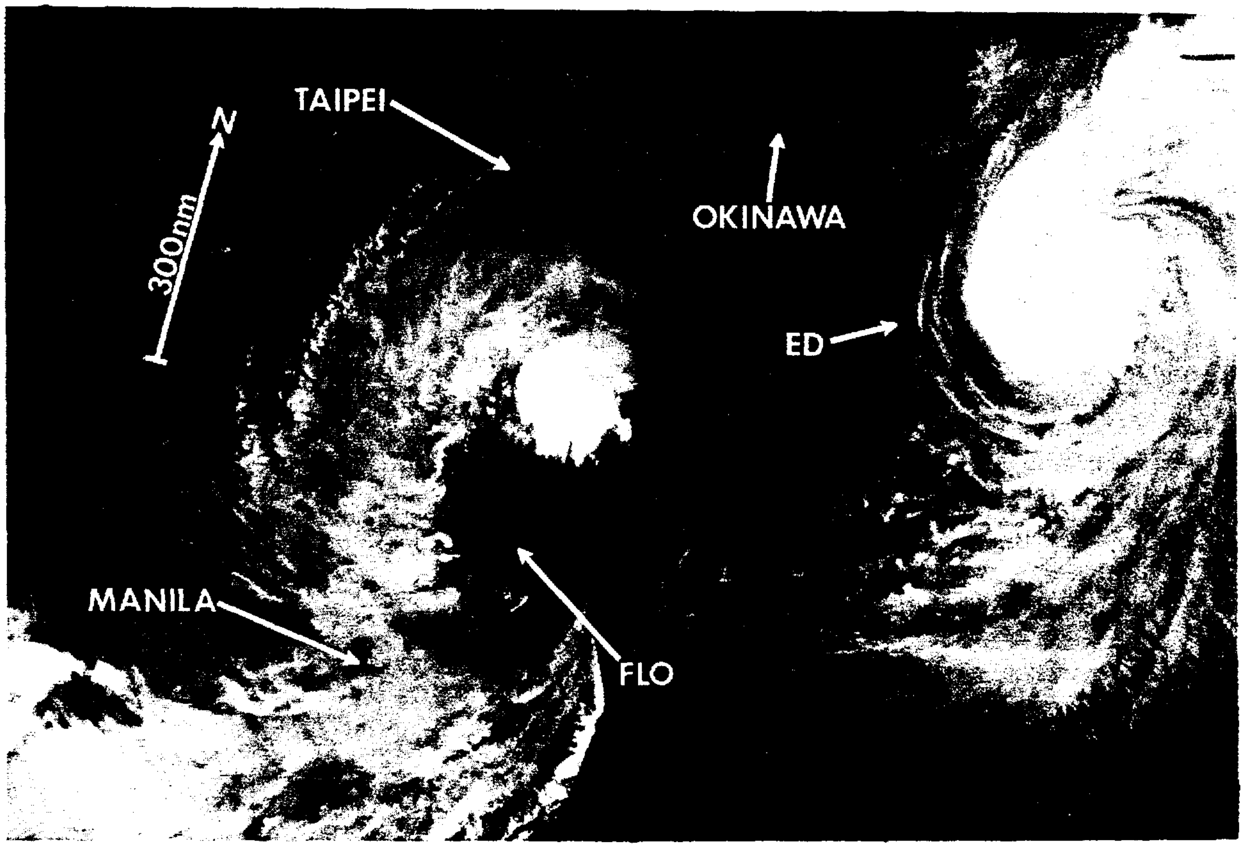


Figure 3-26-1 With the low-level most probably overland and without any central convection, Flo begins its rapid acceleration to the northeast in tandem with Ed (25W) (060640Z October infrared DMSP imagery).

I. HIGHLIGHTS

Forming in the Philippine Sea west Ed (25W), Flo was notable for its binary interaction with Ed. An unanticipated stall, sharp recurvature west of Luzon, and rapid acceleration to the northeast resulted in forecast errors which were the largest of 1993.

II. CHRONOLOGY OF EVENTS

September

280600Z - The disturbance was first mentioned in the Significant Tropical Weather Advisory as a persistent area of convection located within the monsoon trough in the Philippine Sea.

301900Z - Increased deep convection around the well defined low-level circulation center led to issuance of a Tropical Cyclone Formation Alert.

October

011200Z - The first warning was based on a satellite Intensity estimate of 25 kt (13 m/sec).

020000Z - Flo was upgraded to a tropical storm based on the formation of a ragged CDO and resulting satellite intensity estimate of 35 kt (17 m/sec).

031800Z - The appearance of eye and satellite intensity estimate of 65 kt (33 m/sec) led JTWC to upgrade Flo to a typhoon.

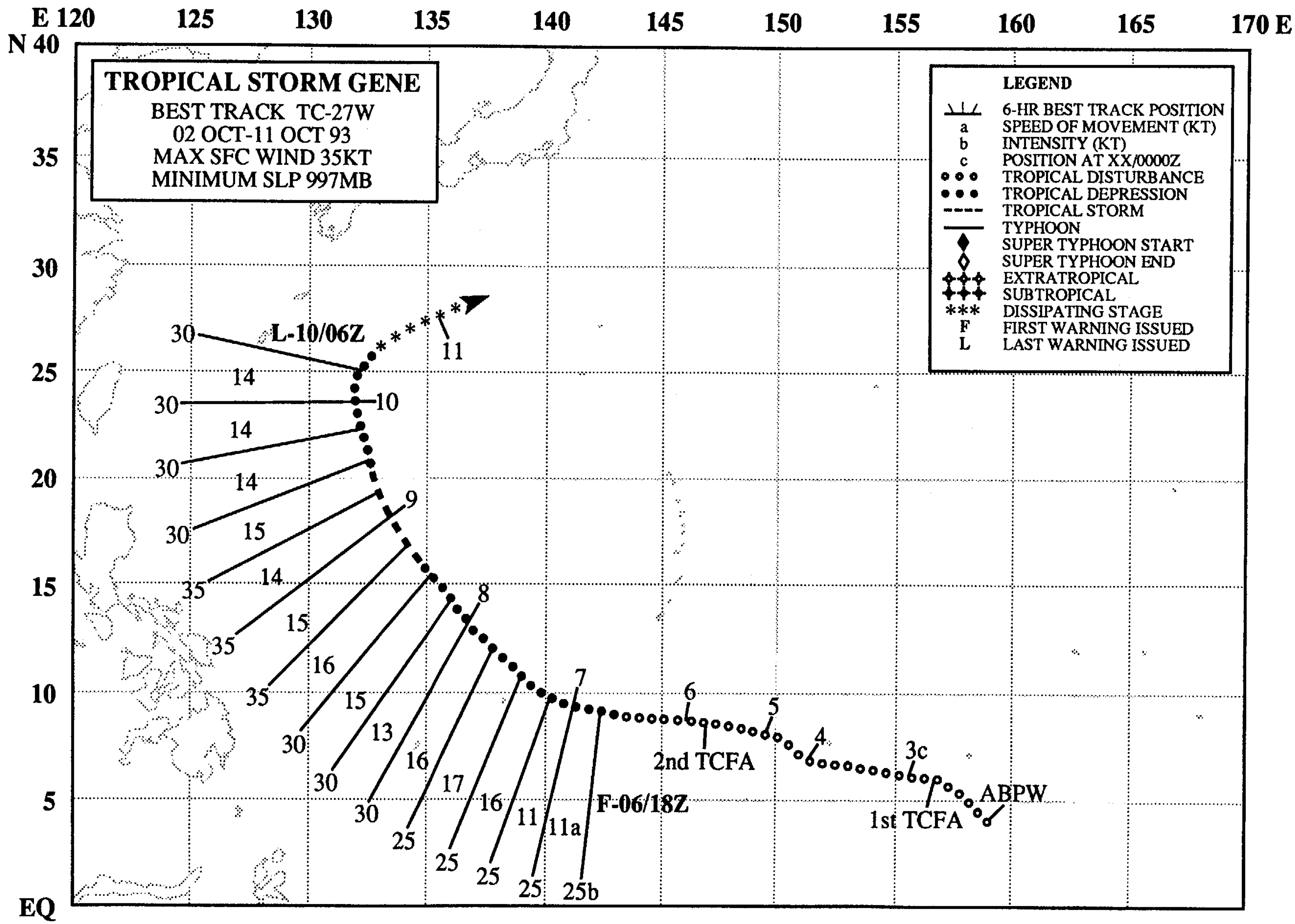
051200Z - Flo unexpectedly recurved, striking Luzon from the west, and afterward, accelerated rapidly toward the northeast.
081800Z - The final warning was issued on Flo as it transitioned into an extratropical low.

III. IMPACT

Torrential rains associated with Flo caused widespread flooding across the island of Luzon in the Philippines. Press reports indicated that at least 50 people were killed or missing, and over 300,000 were evacuated to higher ground. The accelerated motion of Flo, after recurving, to an average speed of 46 kt (85 km/hr) resulted in winds of up to 65 kt (33 m/sec) in the dangerous semicircle. The USS Independence battle group was caught in the dangerous semicircle.

IV. DISCUSSION

A binary interaction occurred between Ed and Flo and appears in the preceding write up on Super Typhoon Ed (25W). With regard to forecast errors, Flo generated the largest 72-hour forecast error — 1732 nm (154 km) — of the year. Flo's stall, loss of central convection (Figure 3-26-1), recurvature and subsequent rapid acceleration compounded the forecasting problem. Objective guidance, including the dynamic models, had difficulty handling the track changes. As these events occurred, forecasters indicated low confidence in their forecasts.


TROPICAL STORM GENE
BEST TRACK TC-27W
02 OCT-11 OCT 93
MAX SFC WIND 35KT
MINIMUM SLP 997MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-10/06Z
F-06/18Z
2nd TCFA
1st TCFA
ABPW

TROPICAL STORM GENE (27W)

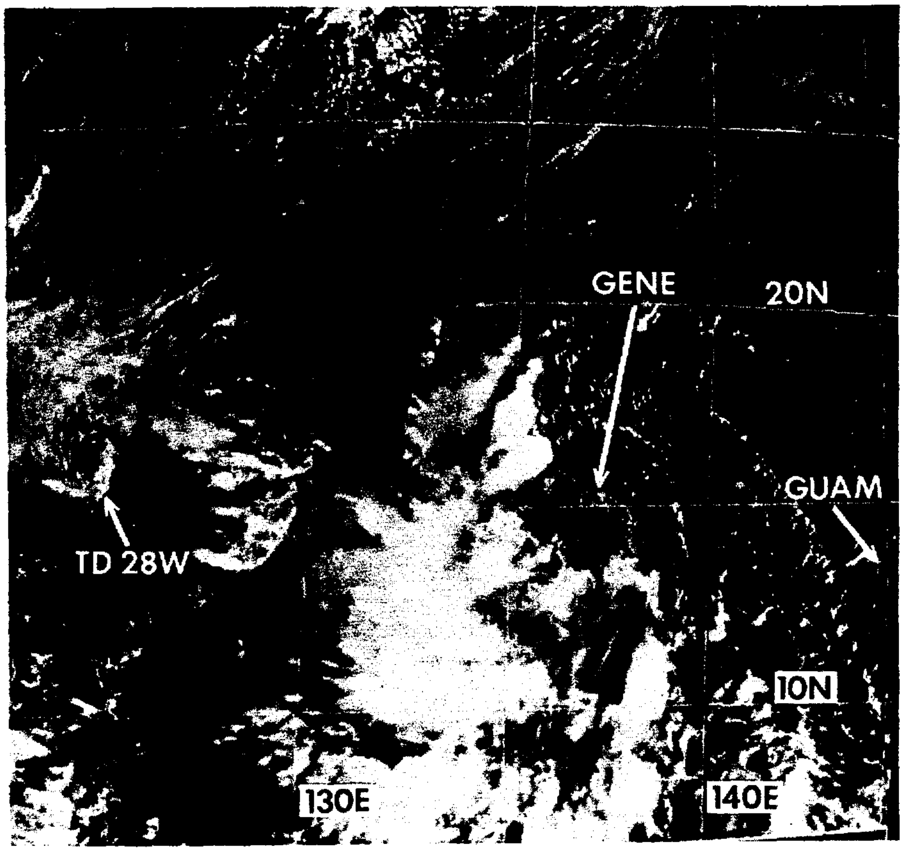


Figure 3-27-1 Cloud lines outline the exposed low-level circulation center of Gene about 12 hours before it was upgraded to tropical storm intensity (080424Z October visible DMSP imagery).

I. HIGHLIGHTS

Occurring during a multiple storm outbreak that included Super Typhoon Ed (25W), Typhoon Flo (26W), and Tropical Depression 28W), Gene was the first of five significant tropical cyclones to form during October. During a four-day evolution, Gene slowly transitioned from a wave in the easterlies into a tropical depression, while passing south of Guam. Briefly attaining tropical storm intensity, Gene (Figure 3-27-1) followed a northward track, and ultimately dissipated over water, east of Okinawa.

II. CHRONOLOGY OF EVENTS

October

020600Z - An area of persistent convection, associated with a wave in the easterlies south of the Caroline Islands, resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

021930Z - Increased convective organization led to the issuance of a Tropical Cyclone Formation Alert (TCFA).

031930Z -A decrease in convection during the TCFA, led to its cancellation.

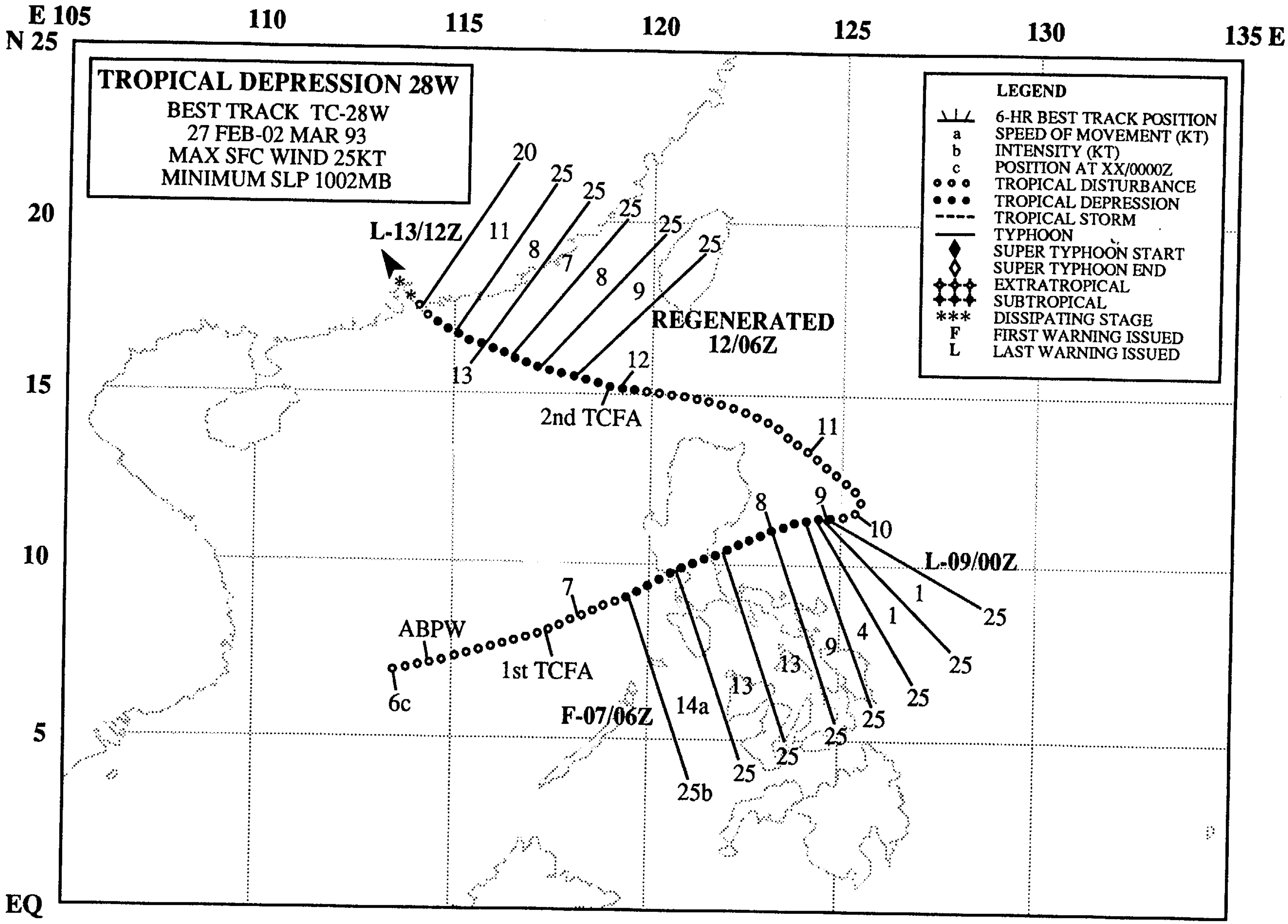
052000Z - Increased convection near the circulation center, prompted the issuance of a second TCFA.

061800Z - The first warning was issued based on a satellite intensity estimate of 25 kt (13 m/sec).

081800Z - Despite strong persistent upper level wind shear, Gene was upgraded to tropical storm intensity based on a satellite intensity estimate of 35 kt (18 m/sec).
100600Z - The final warning was issued on Gene as it dissipated over water east of Okinawa.

III. IMPACT

None.



TROPICAL DEPRESSION 28W
BEST TRACK TC-28W
27 FEB-02 MAR 93
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 105
110
115
120
125
130
135 E
N 25
20
15
10
5
EQ
L-13/12Z
REGENERATED 12/06Z
2nd TCFA
L-09/00Z
ABPW
1st TCFA
F-07/06Z
6c
14a
25b

TROPICAL DEPRESSION 28W

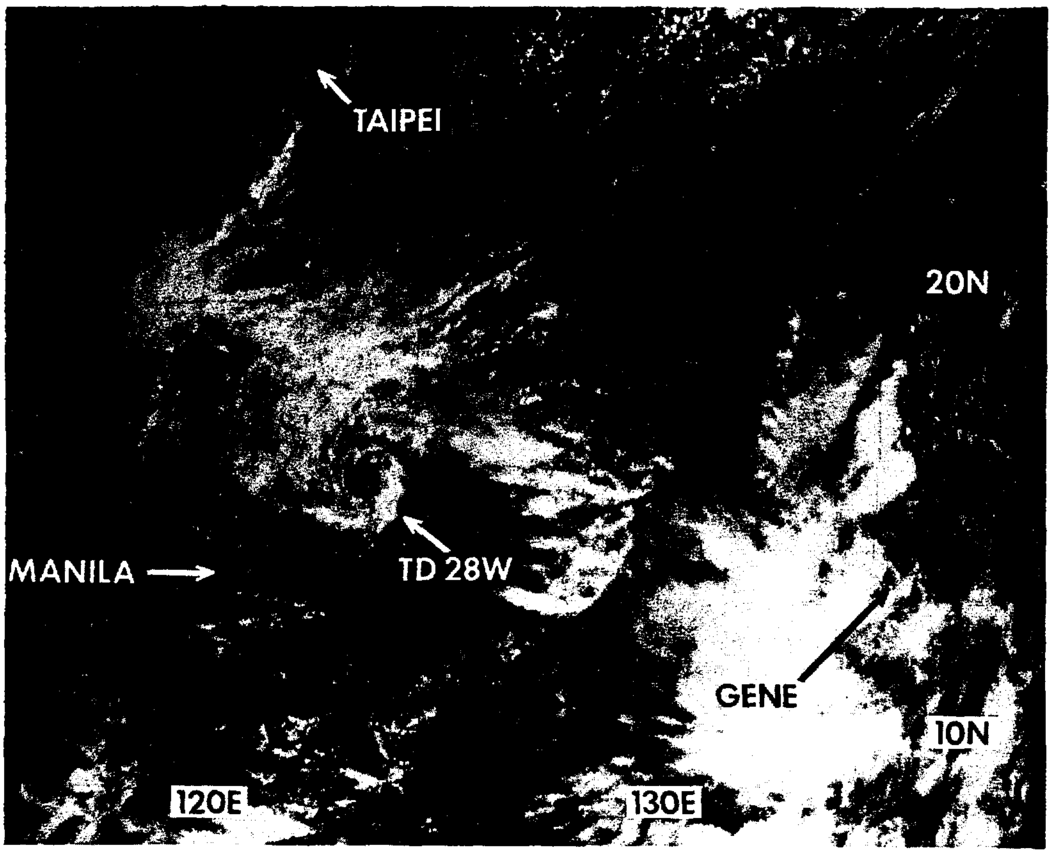


Figure 3-28-1 The exposed low-level circulation center of TD 28W is visible to the east of Luzon. Most of the deep convection associated with the depression subsided after crossing Luzon 12 hours earlier (080424Z October visual DMSP imagery).

I. HIGHLIGHTS

Caught in strong monsoonal flow, Tropical Depression 28W (TD 28W) initially moved northeastward toward Luzon, in the wake of Super Typhoon Ed (25W) and Typhoon Flo (26W). Persistent, yet weak, TD 28W remained at tropical depression intensity while crossing Luzon and moving into the Philippine Sea where it dissipated 24 hours later (Figure 3-28-1). After the remnants of TD 28W turned northwestward on 10 October, the tropical cyclone regenerated. TD 28W made landfall just to the west of Hong Kong and dissipated in southern China.

II. CHRONOLOGY OF EVENTS

October

060600Z - An area of persistent convection within the monsoon trough, near the Vietnam coastline, resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

062000Z - A Tropical Cyclone Formation Alert (TCFA) was issued based on an increase in convection near the circulation center.

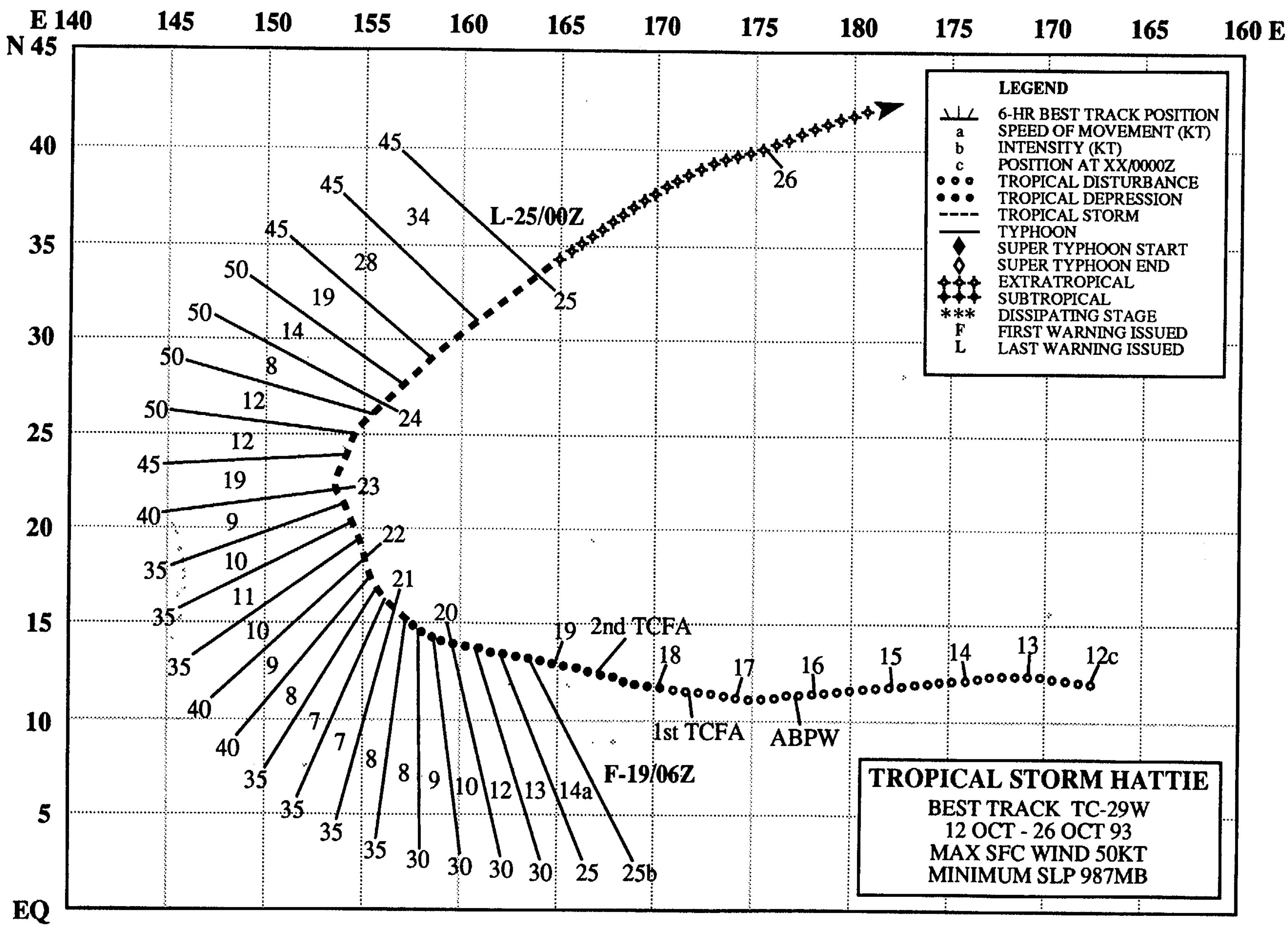
070600Z - The first warning was issued on TD 28W based upon a satellite intensity estimate of 25 kt (13 m/sec).

090000Z - The first final warning was issued as the system dissipated over water, leaving behind a diffuse, low-level circulation center.

120200Z - A second TCFA was issued following flare-ups of intermittent deep convection over the low level circulation center.
120600Z - Warnings were reissued as convective organization improved while the system tracked toward Hong Kong.
131200Z - The final warning of the regenerated system was issued as the system quickly dissipated after passing over land in the vicinity of Hong Kong.

III. IMPACT

None.


E 140
145
150
155
160
165
170
175
180
175
170
165
160 E
N 45
40
35
30
25
20
15
10
5
EQ
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-25/00Z
F-19/06Z
2nd TCFA
1st TCFA
ABPW
12c
14a
25b
TROPICAL STORM HATTIE
BEST TRACK TC-29W
12 OCT - 26 OCT 93
MAX SFC WIND 50KT
MINIMUM SLP 987MB

TROPICAL STORM HATTIE (29W)

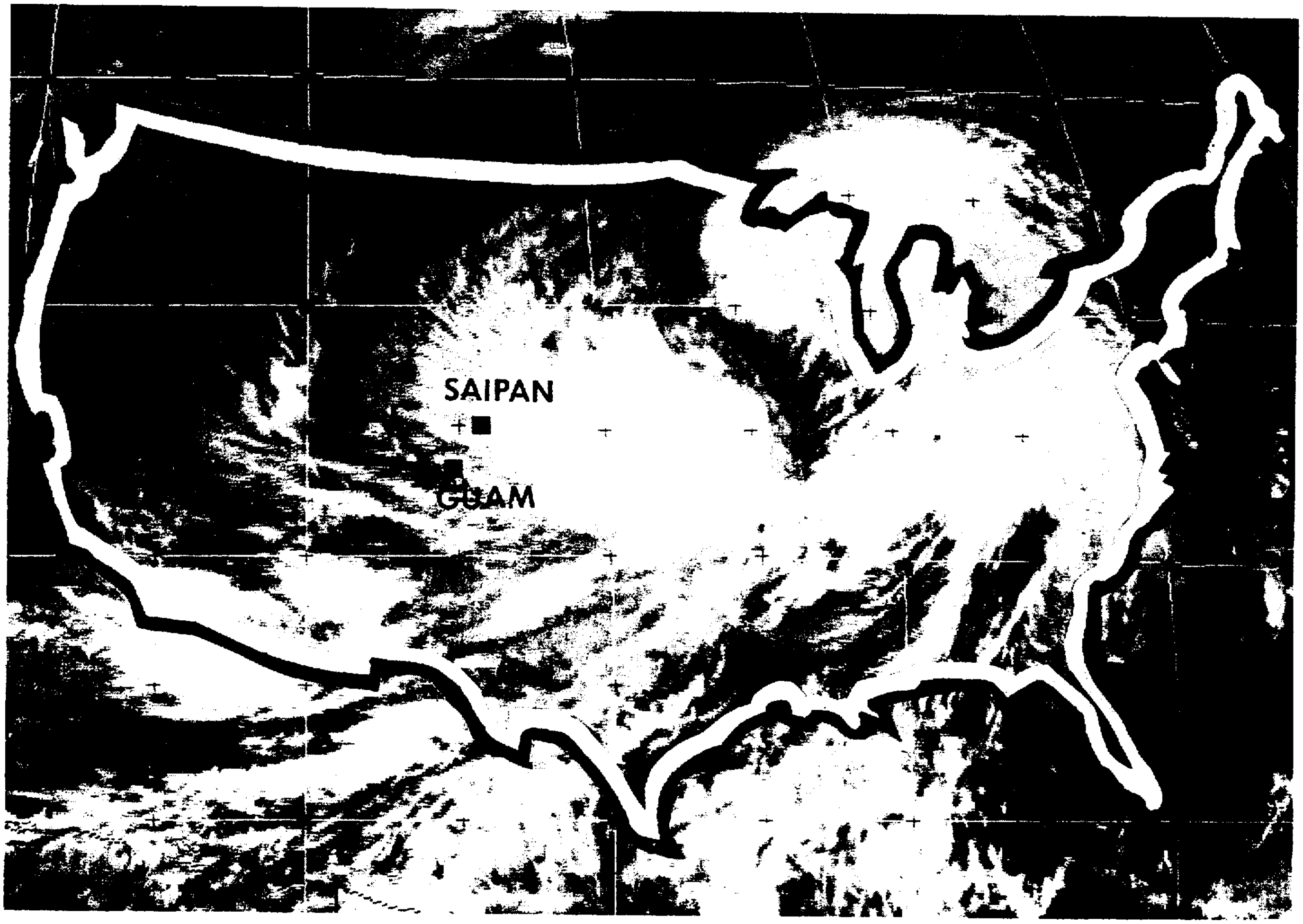


Figure 3-29-1 An outline of the U.S. mainland superimposed (to-scale) upon an infrared image of Hattie (220030Z October infrared GMS imagery).

I. HIGHLIGHTS

Hattie started as a large monsoon depression. Five Tropical Cyclone Formation Alerts were issued — three by the Central Pacific Hurricane Center (CPHC) and two by the JTWC — before the first warning was issued. The system was unique because of its cloud structure: a large 100-160 nm (200-300 km) diameter central area remained relatively cloud-free while convective cloud clusters were peppered throughout the periphery of the circulation in an area equal in size to the continental United States (see Figure 3-29-1).

II. CHRONOLOGY OF EVENTS

October

160600Z - The tropical disturbance was first mentioned of the in the Significant Tropical Weather Advisory as a region of loosely organized convection associated with a large monsoon depression near the international date line.

171630Z - The first JTWC Tropical Cyclone Formation Alert (TCFA) issued was based upon an increase in convection and improved convective curvature.

181630Z - A second TCFA (fifth overall) followed after the system failed to intensify.
190600Z - The first warning was issued based upon numerous synoptic reports of 25 kt (13 m/sec) in a peripheral wind band encircling a large light-wind core.
201800Z - The upgrade to a tropical storm was based upon surface synoptic reports of winds up to 35 kt(13 m/sec) within the peripheral wind band.
250000Z - The final warning was issued on Hattie as it transitioned into an extratropical low.

III. IMPACT

The island of Pohnpei in the eastern Caroline Islands reported minor damage to vegetation and structures.

IV. DISCUSSION

From a diagnostic standpoint, Hattie was one of the most problematical tropical cyclones of 1993. Hattie evolved from a large monsoon depression which formed in the Marshall Islands during mid-October. A "monsoon depression" is distinguished from other types of tropical cyclones by the following characteristics (see also the definition in Appendix A):

1) a large-sized depression in the surface pressure field with a radius of the outermost closed isobar (ROCI) on the order of 300 nm (555 km);

2) extensive amounts of convective cloud elements loosely organized within the confines of the cyclonic vortex; however, the circulation center lacks a persistent convective feature that would lend itself to the Dvorak intensity analysis technique; and,

3) a wind field that features a large, 100-160 nm (200-300 km) diameter, light-wind core which is surrounded wholly, or in part, by bands of higher, 25-35 kt (13-18 m/sec) wind.

The monsoon depression which became Tropical Storm Hattie was large; a composite chart of its sea-level pressure was constructed from surface observations taken during the period 181200Z to 200000Z October (Figure 3-29-2). The ROCI during the composite period was 430 nm (800 km) north-south and 755 nm (1400 km) east-west. The cloud field associated with Hattie during the composite period exhibited a large core region which was relatively cloud free surrounded by extensive clusters and bands of deep cumulonimbus clouds. The structure of the wind field at this time featured a large core of relatively light wind (which was collocated with the relatively cloud-free core in the satellite image) surrounded by an extensive area of 25-30 kt (13-15 m/sec) wind outward for up to 540 nm (1000 km) clockwise from northwest to southwest.

Hattie presented two diagnostic problems to the JTWC. The first problem was that since it lacked persistent central convection, and the Dvorak technique for the estimation of tropical cyclone intensity from satellite imagery does not apply. Attempts were made, however, to apply the technique to one of several of Hattie's persistent peripheral cloud clusters. Finally, however, as Hattie turned northward, a distinct and centrally located low-level circulation center became apparent (Figure 3-29-3), and the Dvorak technique applied.

The second diagnostic problem was determining whether the disturbance (which was to become Hattie) was a monsoon depression or a monsoon gyre (see Appendix A for complete definitions of these terms and Figure 3-29-4). As a monsoon depression, the disturbance would be expected to evolve eventually into a conventional, but large, tropical cyclone. As a monsoon gyre, the disturbance would be expected to evolve into a large "fish-hook" shaped cloud band which would produce a series of small tropical cyclones. In retrospect, the option to go with the synoptic pattern as a monsoon depression was correct.

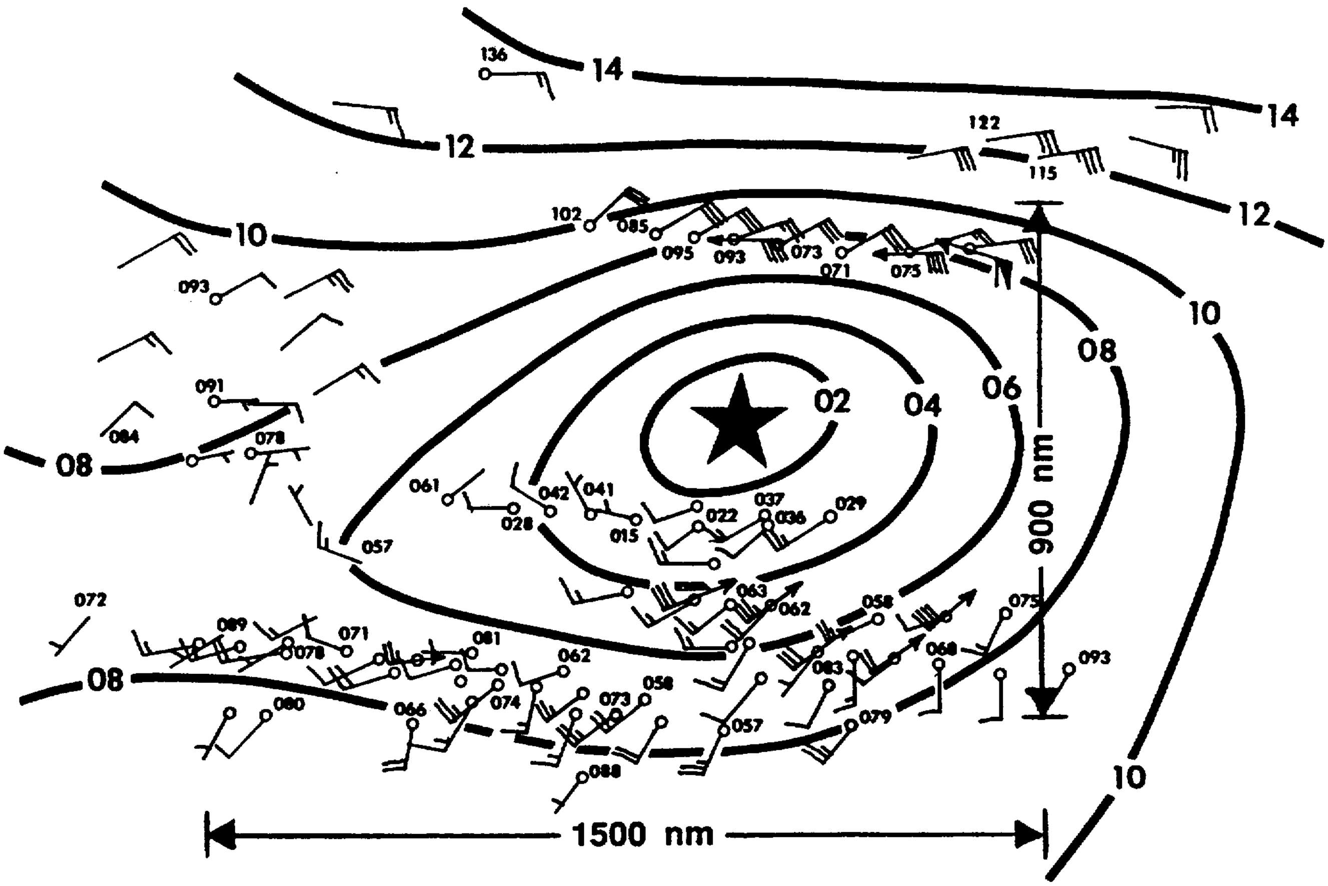


Figure 3-29-2 Isobaric analysis of the sea-level pressure constructed from a composite of observations plotted with respect to the moving center of Hattie (large star). Contour interval is 2 mb, and data are for 181200Z - 200000Z.

In summary, the Dvorak technique shouldn't be applied to monsoon depressions. For the present, the intensity and areal extent of the peripheral winds must be obtained from conventional synoptic data or from cloud-drift winds. A Dvorak-type technique could be developed to address intensity estimation and wind distribution in the monsoon depression. Other spectral windows than the visual and infrared, such as the SSM/I, may be exploited. The differential diagnosis between "monsoon depression" and "monsoon gyre" is important for its forecast implications; and, in the case of Hattie, a careful analysis of the structural characteristics led to a useful diagnosis of the pre-Hattie disturbance as a monsoon depression.

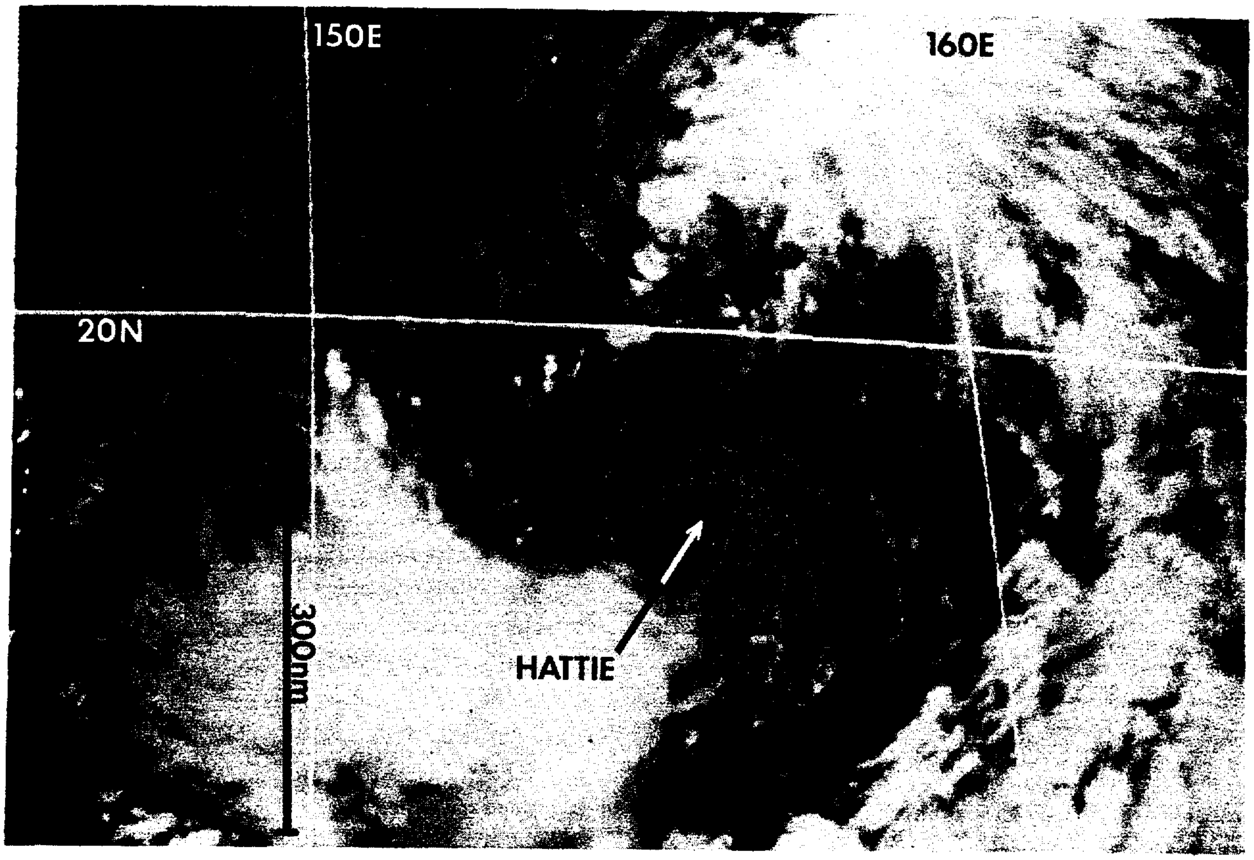


Figure 3-29-3 Hattie's exposed low-level circulation center (LLCC) appears between two areas of extensive convective cloudiness (220031Z October multispectral visual/infrared GMS imagery).

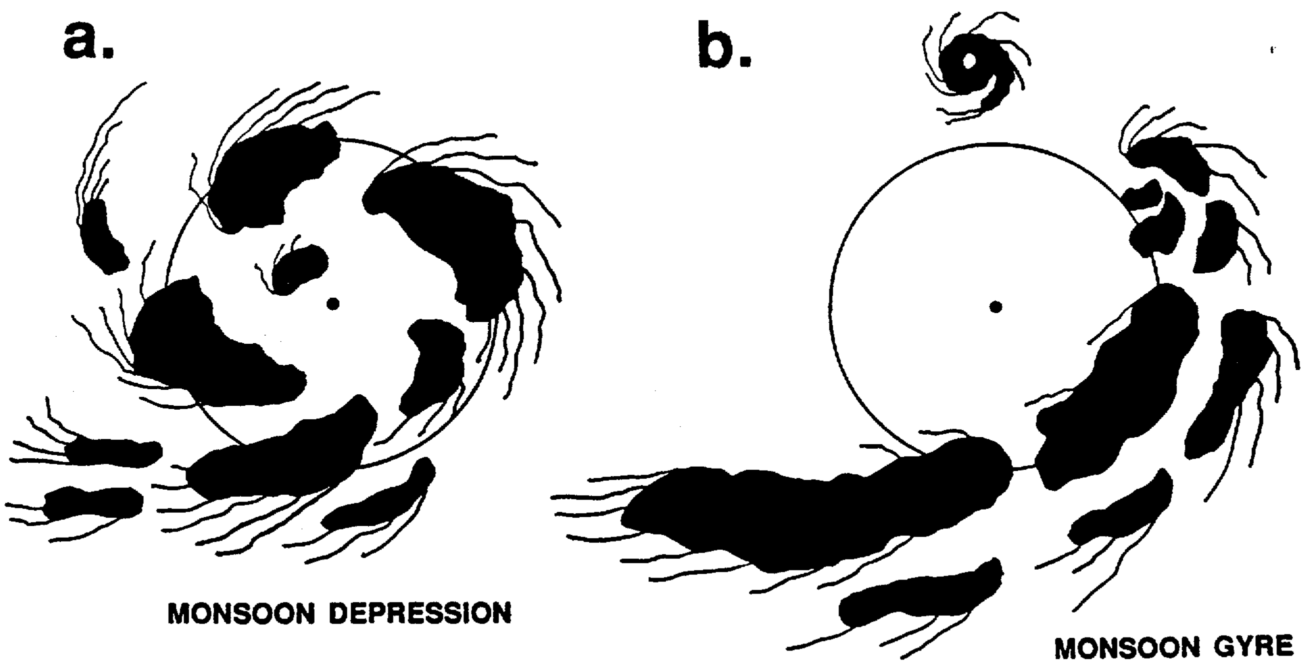
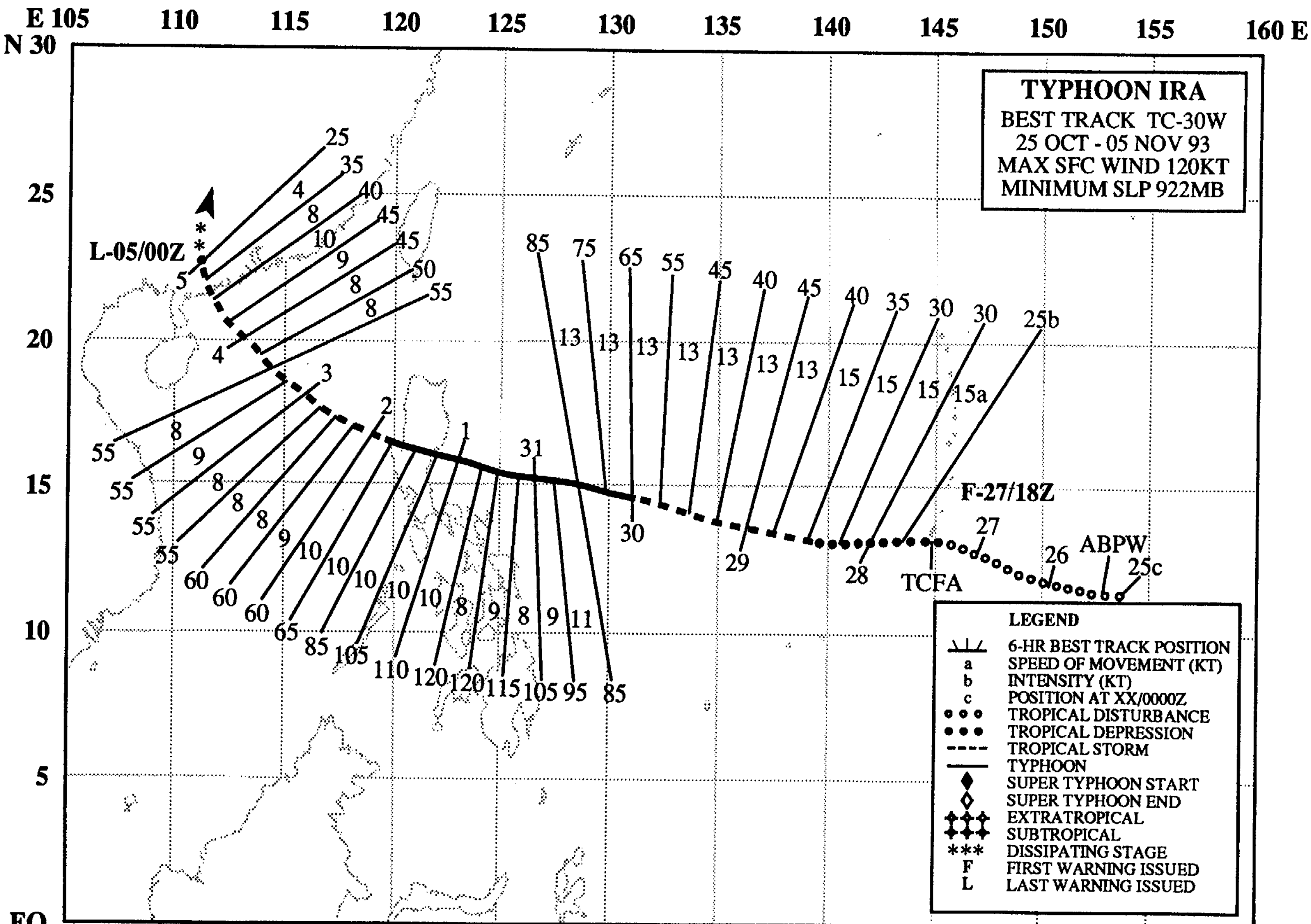


Figure 3-29-4 Schematic illustration of the distribution of deep convective cloud and cirrus in: a) a monsoon depression, and b) a monsoon gyre. Black areas represent deep convection, and filaments indicate orientation of cirrus plumes. Circle enclosed area of lowest sea-level pressure and has a diameter of approximately 600 nm (1110 km). The black dot is the low-level circulation center.


TYPHOON IRA
BEST TRACK TC-30W
25 OCT - 05 NOV 93
MAX SFC WIND 120KT
MINIMUM SLP 922MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-05/00Z
F-27/18Z
TCFA
ABPW
E 105
110
115
120
125
130
135
140
145
150
155
160 E
N 30
25
20
15
10
5
EQ

TYPHOON IRA (30W)

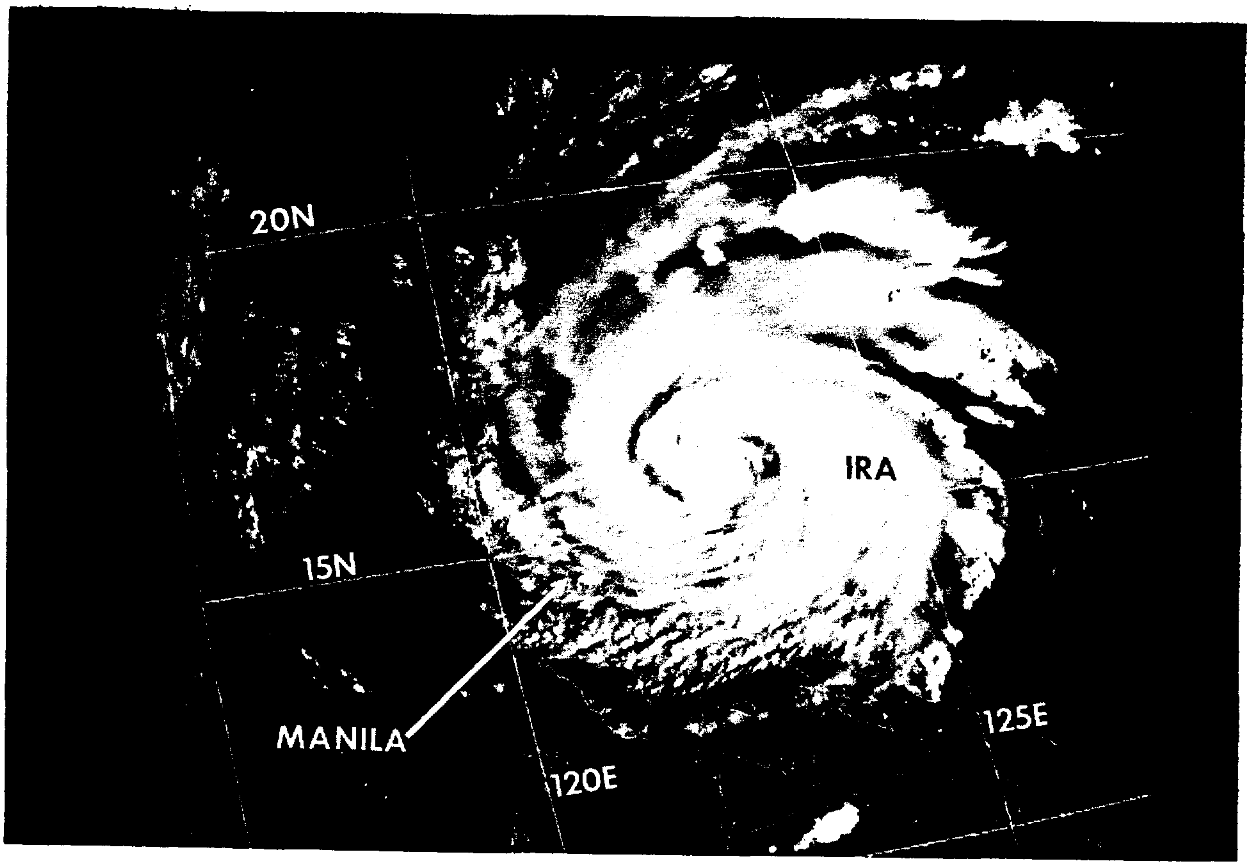


Figure 3-30-1 Typhoon Ira shortly before making landfall in Luzon with maximum sustained winds estimated at 110 kt (57 m/sec) (010121Z November visible DMSP imagery).

I. HIGHLIGHTS

The final tropical cyclone to form during October, Ira, passed directly over Luzon at typhoon intensity and followed a westward track (Figure 3-30-1). Upon entering the South China Sea, a weaker Ira turned toward southern China and made landfall three days later southwest of Hong Kong.

II. CHRONOLOGY OF EVENTS

October

250600Z - An area of persistent convection associated with a weak cyclonic circulation within the monsoon trough, north of the Caroline Islands, resulted in the initial identification of the disturbance in the Significant Tropical Weather Advisory.

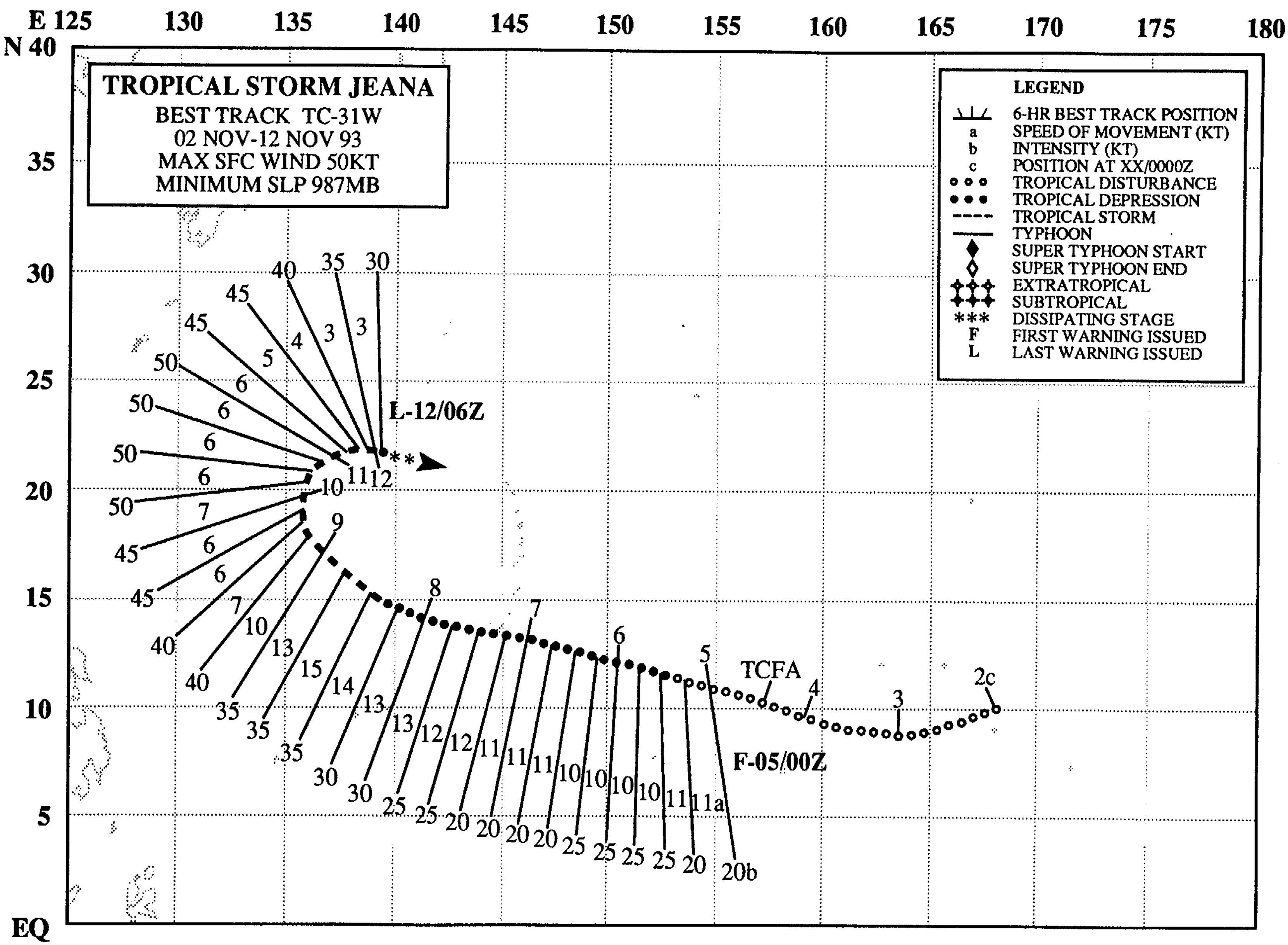
271200Z - A Tropical Cyclone Formation Alert was issued based on an increase in convection and convective curvature, evident in both infrared satellite imagery and on the NEXRAD Doppler Radar located on Guam.

271800Z - The basis of thefirst warning was a satellite intensity estimate of 25 kt (13 m/sec) and Doppler radar velocity information which indicated winds ranging from 22-30 kt (11-15 m/sec) at altitudes of 1500 to 16,000 feet (460 to 4900 meters) above sea level.

281200Z - Based on a satellite intensity estimate of 35 kt (18 m/sec), Ira was upgraded to a tropical storm.
300000Z - Ira was upgraded to a typhoon based on a satellite intensity estimate of 77 kt (40m/sec).
November
050000Z - The final warning was issued after the system made landfall in southern China where it rapidly dissipated.

III. IMPACT

News reports attributed eight deaths in the Philippines to Typhoon Ira's trek across central Luzon. In addition, heavy rains associated with the typhoon also caused extensive flooding in low-lying areas of Luzon.


TROPICAL STORM JEANA
BEST TRACK TC-31W
02 NOV-12 NOV 93
MAX SFC WIND 50KT
MINIMUM SLP 987MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-12/06Z
F-05/00Z
TCFA
E 125
130
135
140
145
150
155
160
165
170
175
180
N 40
35
30
25
20
15
10
5
EQ

TROPICAL STORM JEANA (31W)

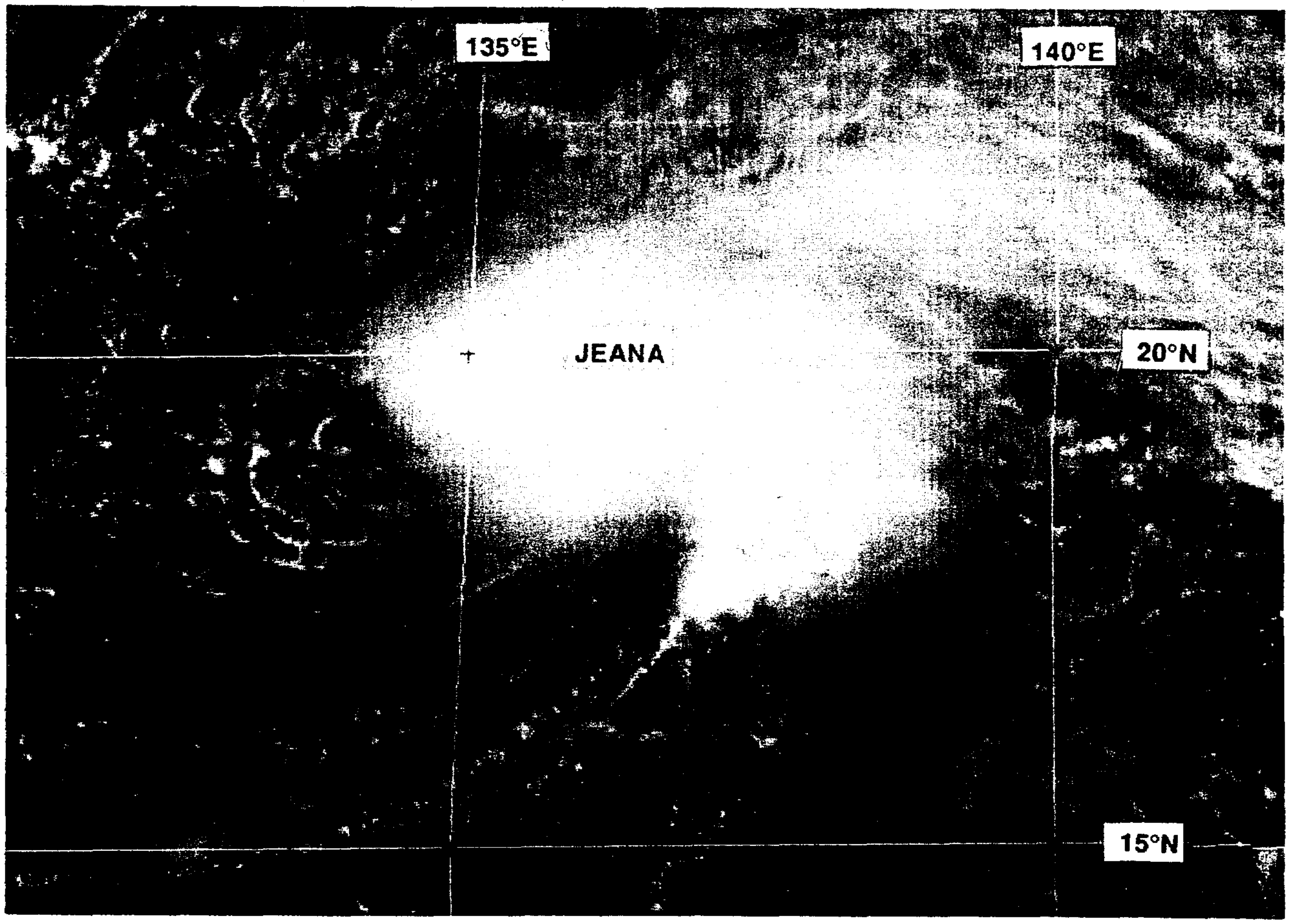


Figure 3-31-1 Still maintaining tropical storm intensity, Jeana begins to weaken as its low-level circulation becomes partially exposed (100531Z November visual GMS imagery).

I. HIGHLIGHTS

The first of four significant tropical cyclones to form during November, Tropical Storm Jeana reached its peak intensity at recurvature and dissipated (Figure 3-31-1). The NEXRAD Doppler radar was instrumental in tracking Jeana during its formative stages near and over Guam.

II. CHRONOLOGY OF EVENTS

November

022300Z - An area of persistent convection within the monsoon trough and near Kwajalein resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

041100Z - A Tropical Cyclone Formation Alert was issued after convection, consolidated near the circulation center.

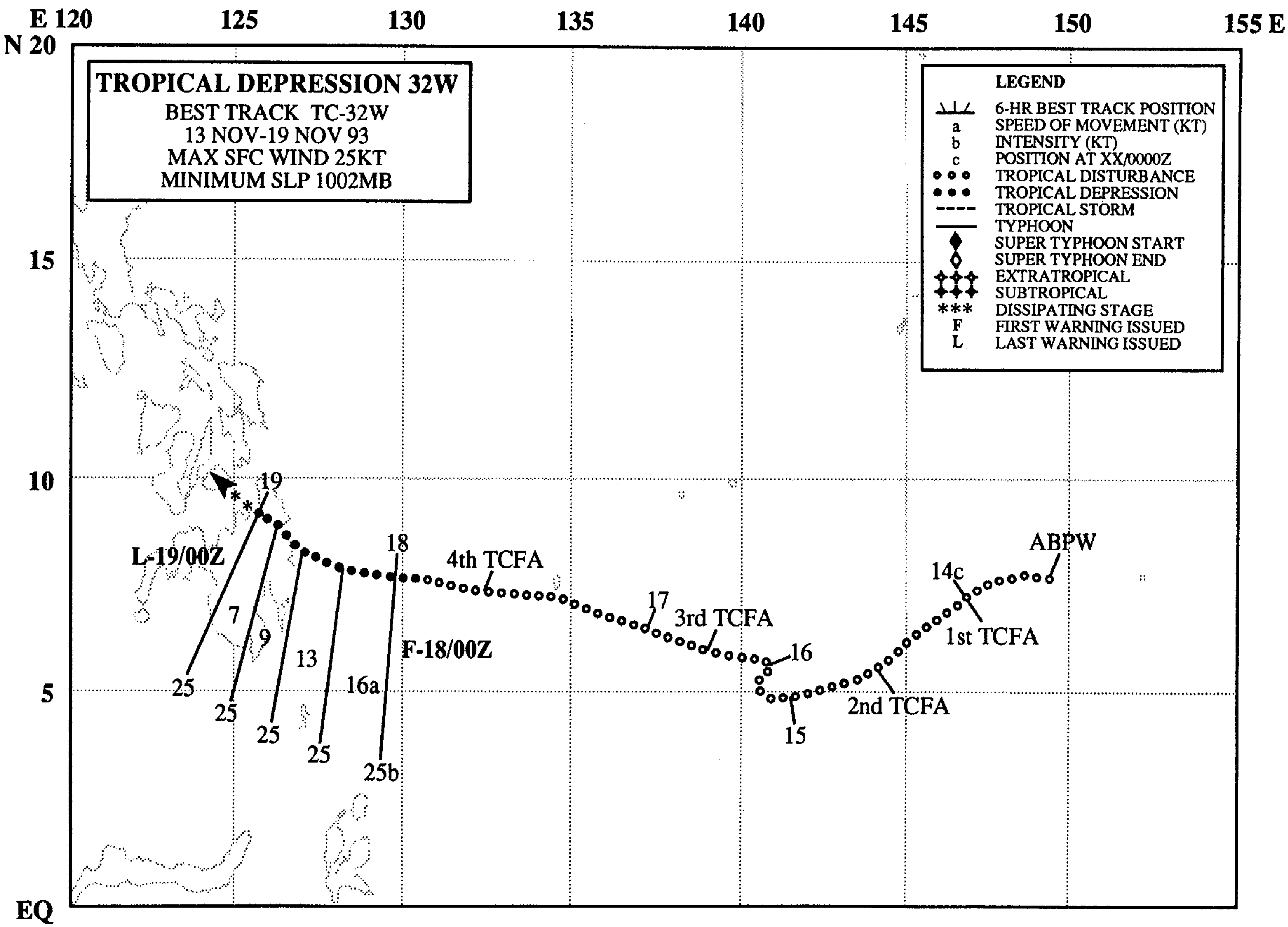
050000Z - The first warning was issued on Tropical Depression 31W based on increased convective curvature and the first daylight visual satellite imagery which indicated an intensity of 25 kt (13 m/sec

060000Z - Based on a satellite intensity estimate of 30 kt (15 m/sec) and the occurrence of intense con

vection near the circulation center, Jeana was upgraded to a tropical storm. Post-analysis of synoptic and satellite data indicates that Jeana more likely became a tropical storm at 081200Z.
120600Z - The final warning was issued on Jeana as it dissipated over water northwest of the Mariana Islands.

III. IMPACT

None.


TROPICAL DEPRESSION 32W
BEST TRACK TC-32W
13 NOV-19 NOV 93
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 120
125
130
135
140
145
150
155 E
N 20
15
10
5
EQ
19
18
17
16
15
14c
L-19/00Z
F-18/00Z
4th TCFA
3rd TCFA
2nd TCFA
1st TCFA
ABPW
7
9
13
16a
25
25
25
25
25b

TROPICAL DEPRESSION 32W

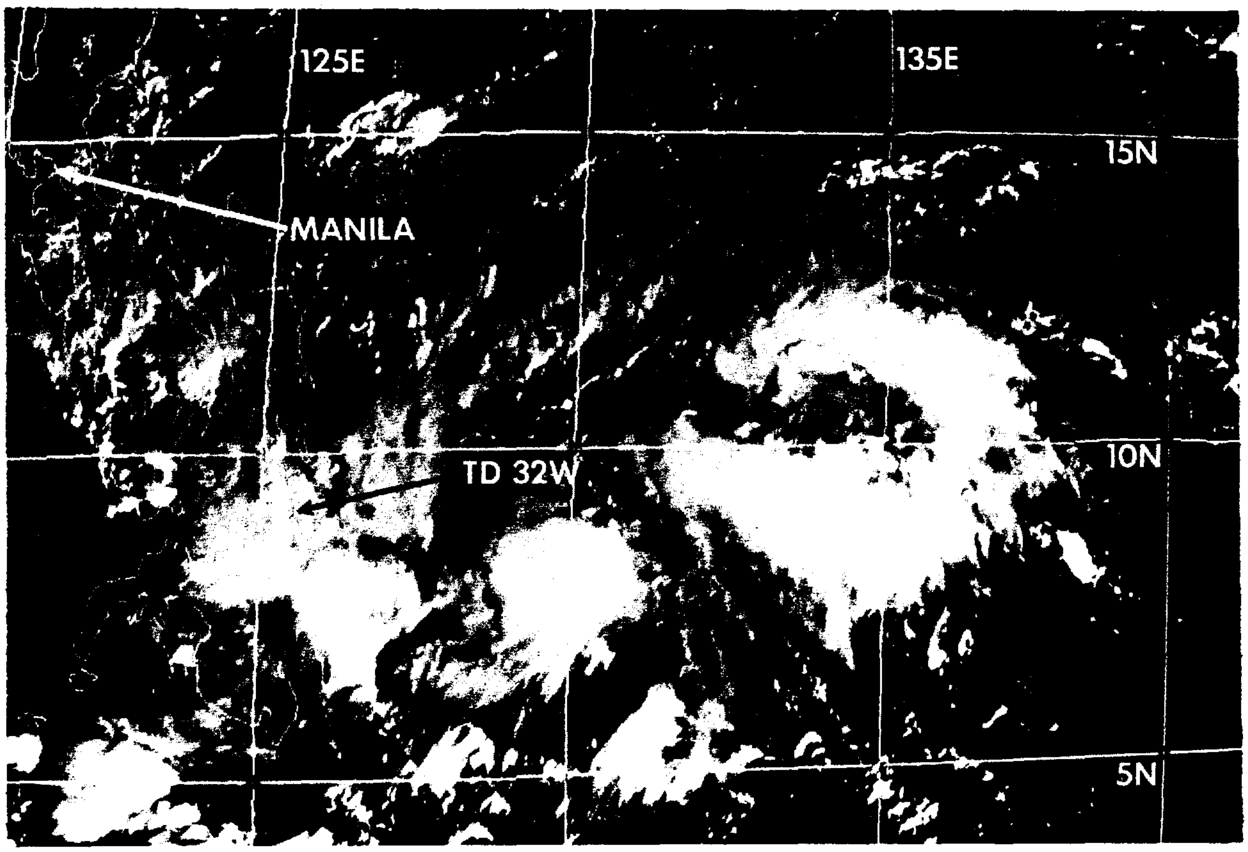


Figure 3-32-1 The remnants of TD 32W move into the southern Philippine Islands (182330Z November visual GMS imagery).

I. HIGHLIGHTS

Forming in the monsoon trough east of the international date line, Tropical Depression 32W was short-lived as a significant tropical cyclone despite going through a long consolidation stage. The weak, yet persistent disturbance required four Tropical Cyclone Formation Alerts before the first tropical depression warning was finally required.

II. CHRONOLOGY OF EVENTS

November

130600Z - An area of persistent convection within the monsoon trough resulted in the initial identification of the disturbance in the Significant Tropical Weather Advisory.

140000Z - A Tropical Cyclone Formation Alert (TCFA) was issued based on improved convective curvature and organization.

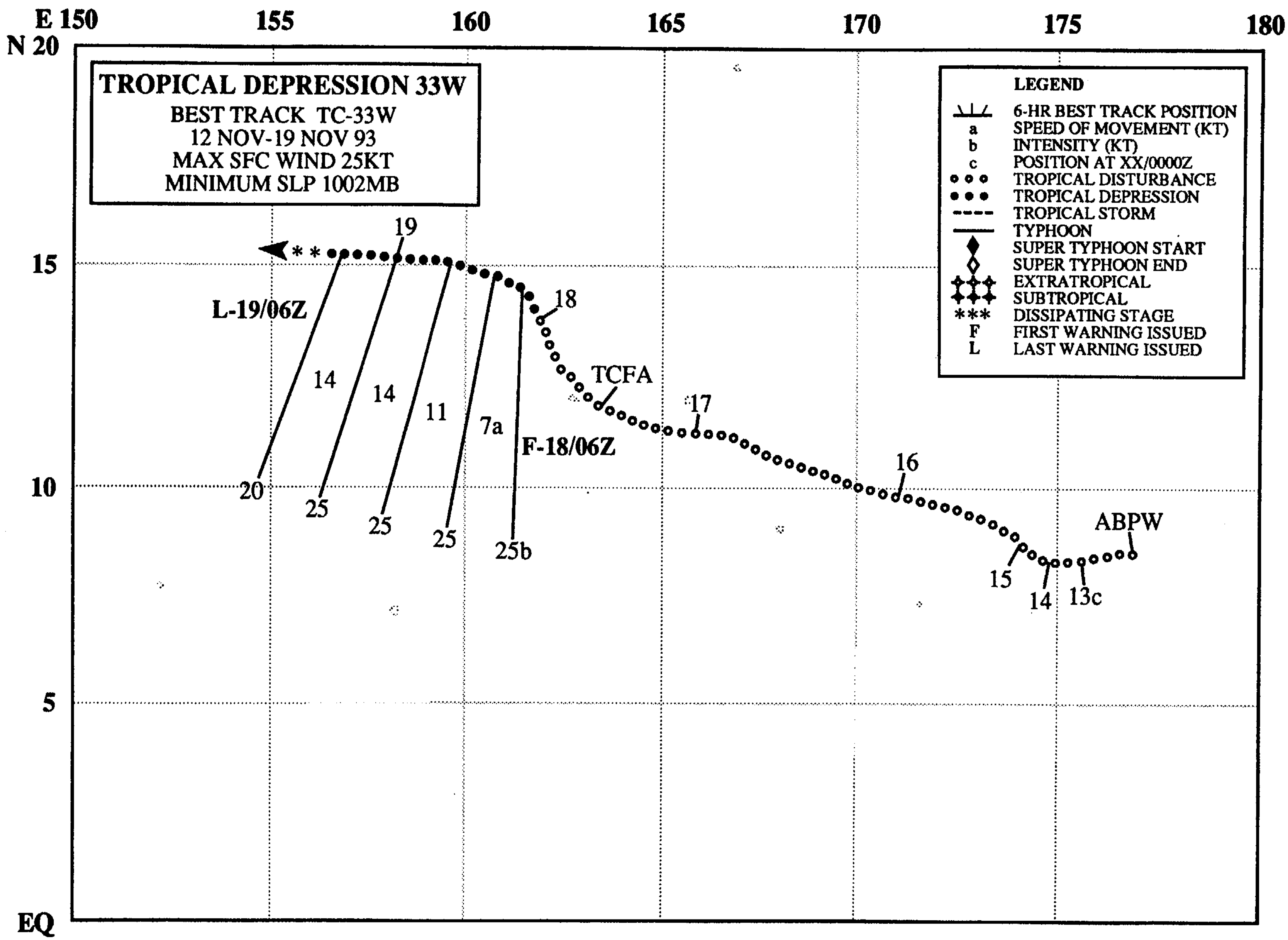
141400Z - The TCFA was reissued based upon a satellite position fix which indicated the system center had reorganizedto the south.

151400Z - The TCFA was canceled after all the deep convection associated with the circulation center had dissipated.

161630Z - A third TCFA was issued following a rapid increase in convective organization as the disturbance tracked westward towards the Philippines.
171630Z - The fourth TCFA was issued once the areal extent of convection increased and organization had slowly improved.
180000Z - The first warning was issued based on visible satellite imagery which indicated that the depression had a well-defined, although exposed, low level circulation center and an estimated intensity of 25 kt (13 m/sec).
190000Z - The final warning reflected the system's dissipation after its passage over Mindanao (Figure 3-32-1).

III. IMPACT

None.


TROPICAL DEPRESSION 33W
BEST TRACK TC-33W
12 NOV-19 NOV 93
MAX SFC WIND 25KT
MINIMUM SLP 1002MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 150
155
160
165
170
175
180
N 20
15
10
5
EQ
L-19/06Z
F-18/06Z
TCFA
ABPW
19
18
17
16
15
14
13c
14
14
11
7a
20
25
25
25
25b

TROPICAL DEPRESSION 33W

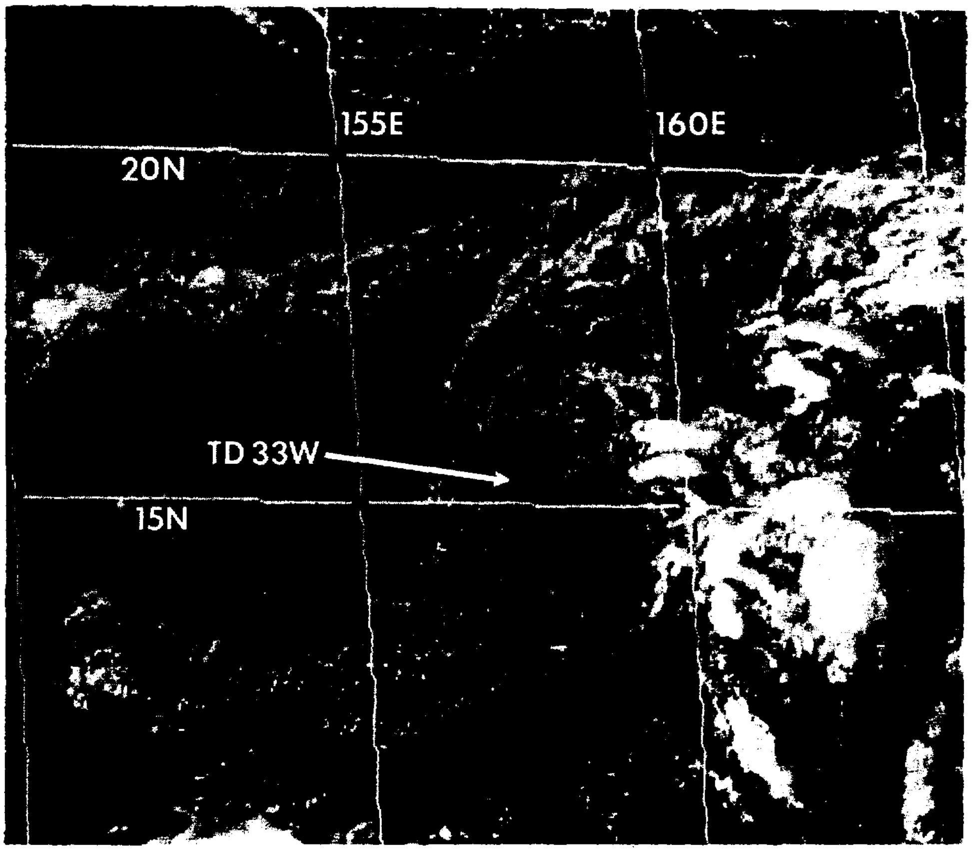


Figure 3-33-1 The only deep convection associated with TD 33W remains to the east of the exposed low-level circulation (182230Z November visual GMS imagery).

I. HIGHLIGHTS

The third tropical cyclone to form during November, Tropical Depression 33W (TD 33W) was another short-lived system which formed at nearly the same time as TD 32W. Development of depression was hampered by persistent vertical wind shear (Figure 3-33-1). TD 33W, was in warning status for only 18 hours.

II. CHRONOLOGY OF EVENTS

November

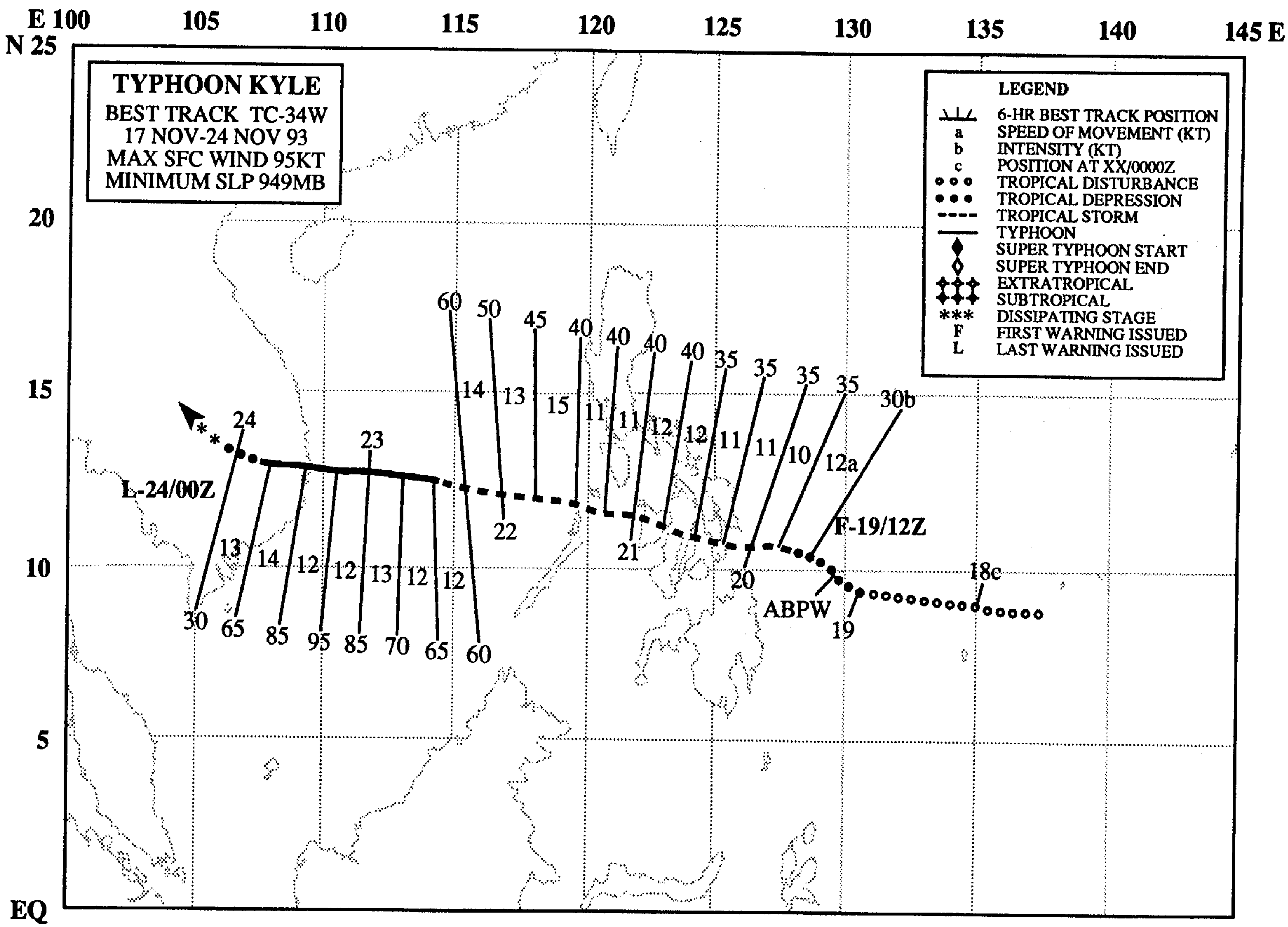
120600Z - An area of persistent convection within the monsoon trough andeast of Majuro in the Marshall Islands resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

171130Z - Issuance of a Tropical Cyclone Formation Alert was issued reflected the prescence of increased convective organization.

180600Z - The first warning was issued based on improved convective curvature and a satellite intensity estimate of 25 kt (13 m/sec).

190600Z - The final warning was issued on TD 33W as it dissipated over water.

III. IMPACT


TYPHOON KYLE
BEST TRACK TC-34W
17 NOV-24 NOV 93
MAX SFC WIND 95KT
MINIMUM SLP 949MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 100
105
110
115
120
125
130
135
140
145 E
N 25
20
15
10
5
EQ
L-24/00Z
F-19/12Z
ABPW
18c
19
20
21
22
23
24
30b
12a

TYPHOON KYLE (34W)

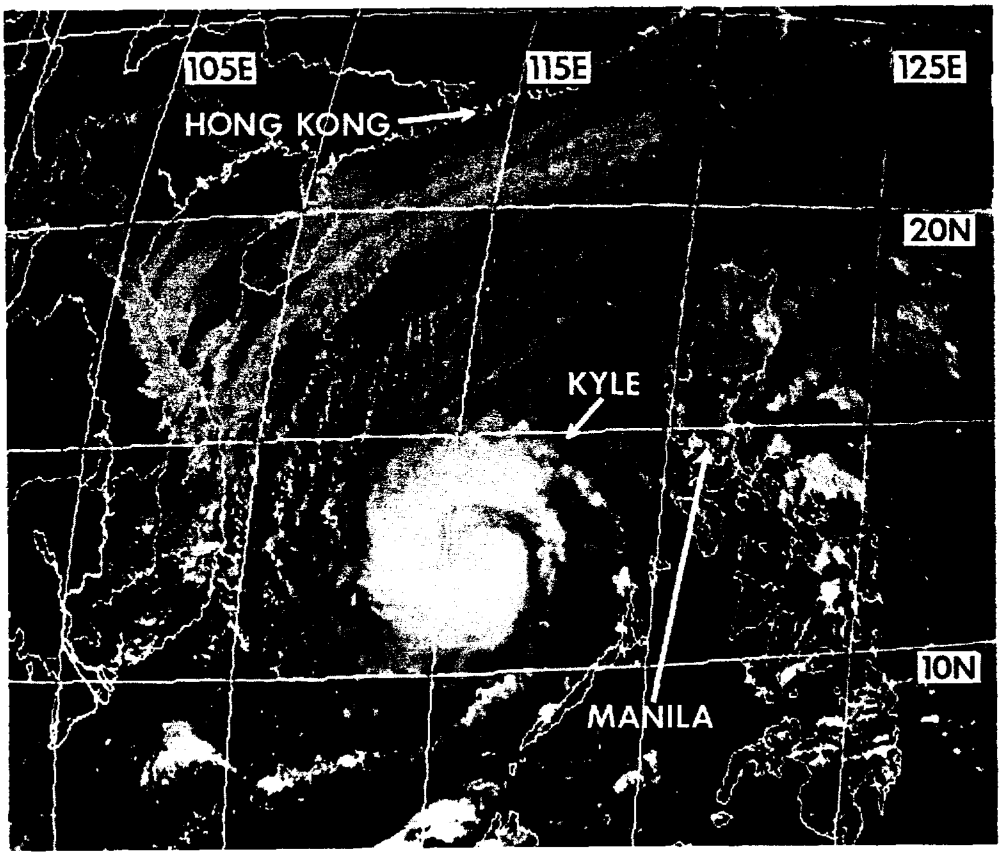


Figure 3-34-1 Over the warm waters of the South China Sea, Kyle rapidly approaches typhoon intensity (220530Z November visual GMS imagery).

I. HIGHLIGHTS

Initially developing from a monsoon depression, Typhoon Kyle was the only one of three significant tropical cyclones that formed during November to reach typhoon intensity. It developed rapidly near Palau, then slowly intensified while crossing the Philippines. Upon entering the South China Sea, Kyle quickly intensified (Figure 3-34-1) into a typhoon, and reached a peak intensity of 95 kt (49 m/sec) prior to landfall in central Vietnam.

II. CHRONOLOGY OF EVENTS

November

190600Z - An area of persistent convection associated with a monsoon depression resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

191200Z - The first warning, based on a satellite intensity estimate of 30 kt (15 m/sec), was issued without a Tropical Cyclone Formation Alert in effect.

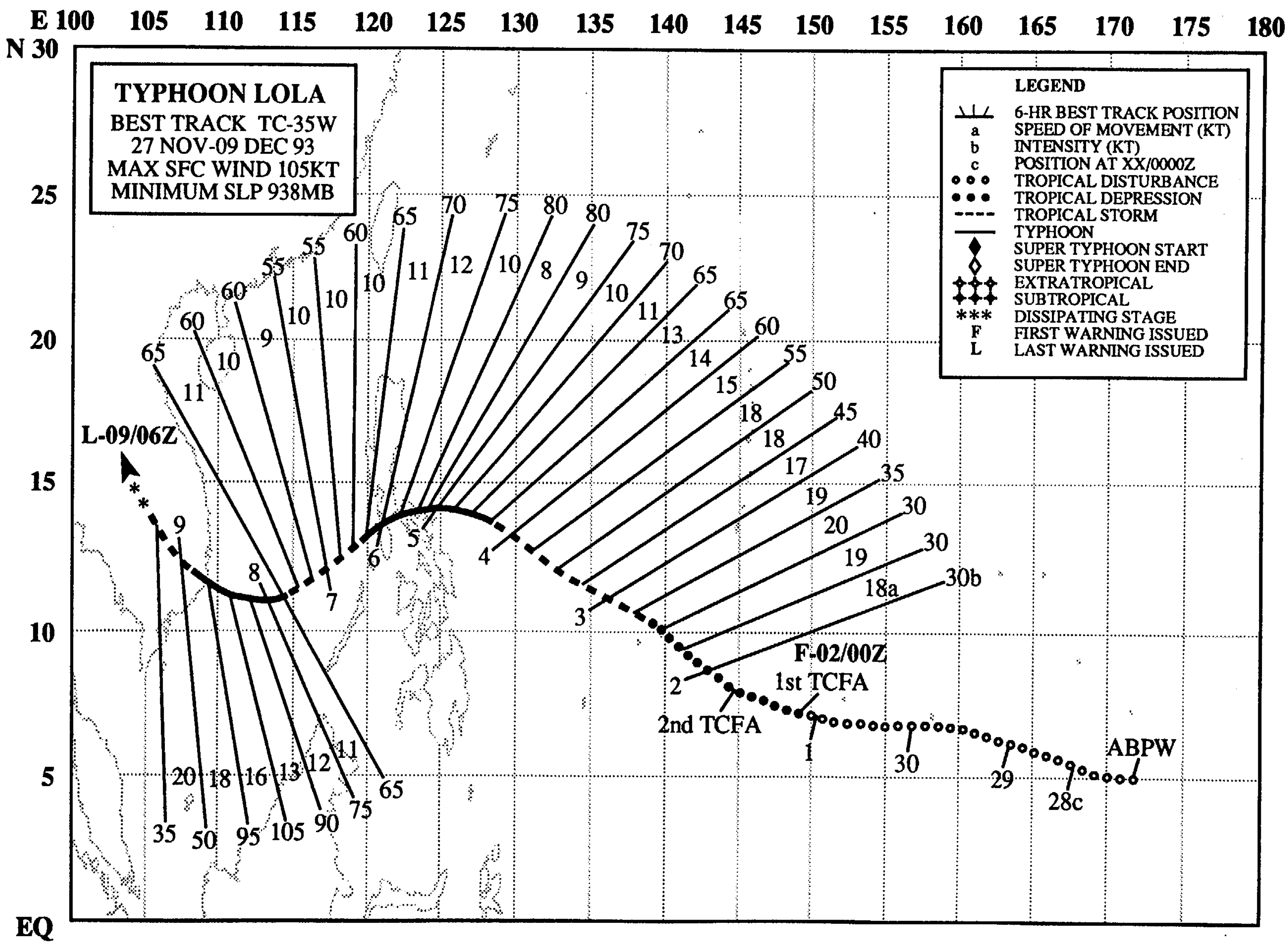
191800Z - The appearance of tighter convective curvature and a satellite intensity estimate of 35 kt (18 m/sec), led to Kyle's upgrad to a tropical storm.

221200Z - The development of an elongated eye and a satellite intensity estimate of 77 kt (40 m/sec), prompted forecasters to upgrade Kyle to a typhoon.

240000Z - The final warning was issued on Kyle as it was dissipating near the Cambodia-Thailand border.

III. IMPACT

News sources indicated that Kyle was responsible for 106 deaths occurred and 59 missing people in four southern Vietnamese provinces. In addition, damage to fisheries, agriculture, and infrastructure in Vietnam was estimated at (US)$1.5 million.



TYPHOON LOLA
BEST TRACK TC-35W
27 NOV-09 DEC 93
MAX SFC WIND 105KT
MINIMUM SLP 938MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-09/06Z
F-02/00Z
1st TCFA
2nd TCFA
ABPW

TYPHOON LOLA (35W)

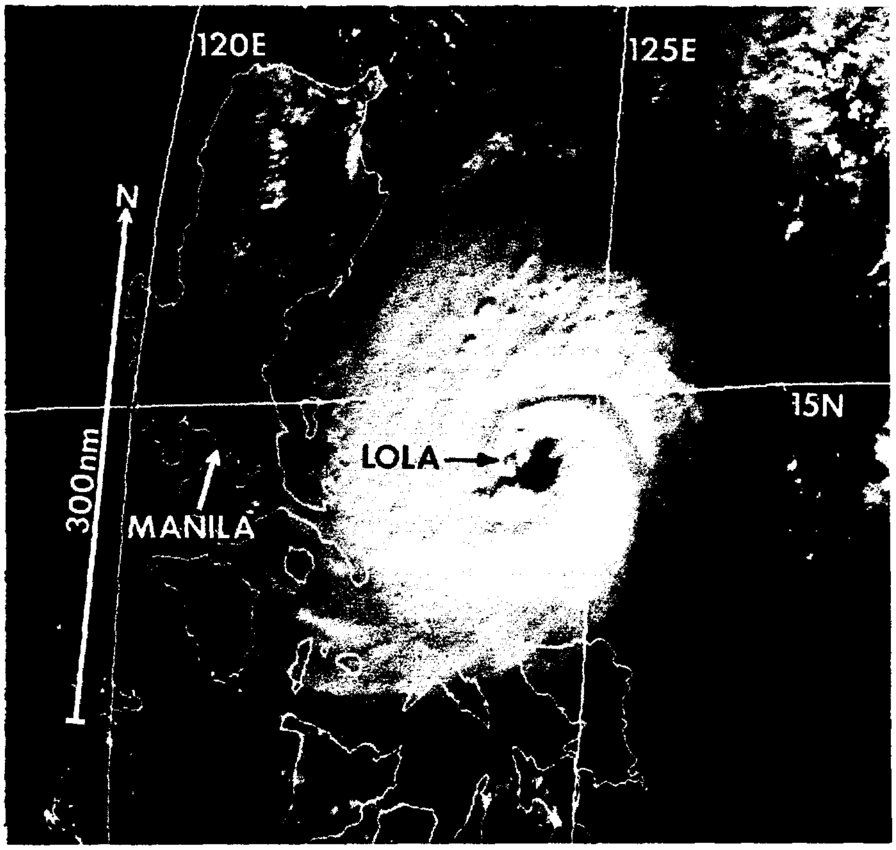


Figure 3-35-1 Lola with a 20 nm (35 km) diameter eye approaches southern Luzon (051230Z December visual GMS imagery.)

I. HIGHLIGHTS

Forming in an active near equatorial trough that ultimately produced three late-season typhoons, Lola slowly intensified to 80 kt (41 m/sec) before crossing the heavily populated Bicol region of southern Luzon (Figure 3-35-1). After killing hundreds of people and displacing more than half-a-million, the typhoon headed toward the southwest, tracing a sinusoidal path across the South China Sea. Lola rapidly reintensified over the South China Sea before moving over southern Vietnam.

II. CHRONOLOGY OF EVENTS

November

270600Z - An isolated area of persistent convection near the western Marshall Islands resulted in the first discussion of the disturbance in the Significant Tropical Weather Advisory.

December

010400Z - A TCFA was issued based on a consolidation of convection near the circulation center.

011900Z - A second TCFA was issued when the disturbance accelerated and moved out of the original TCFA area.

020000Z - The first warning was based on increased convective organization and a satellite intensity estimate of 30 kt (15 m/sec).

030000Z - As a result of a satellite intensity estimate of 45 kt (23 m/sec), Lola was upgraded to a tropical storm. Post analysis of synoptic and satellite data indicate that Lola probably attained tropical storm intensity at 021800Z.

040600Z - The appearance of an eye and a satellite intensity estimate of 65 kt (33 m/sec) led forecasters to upgrade Lola to a typhoon.

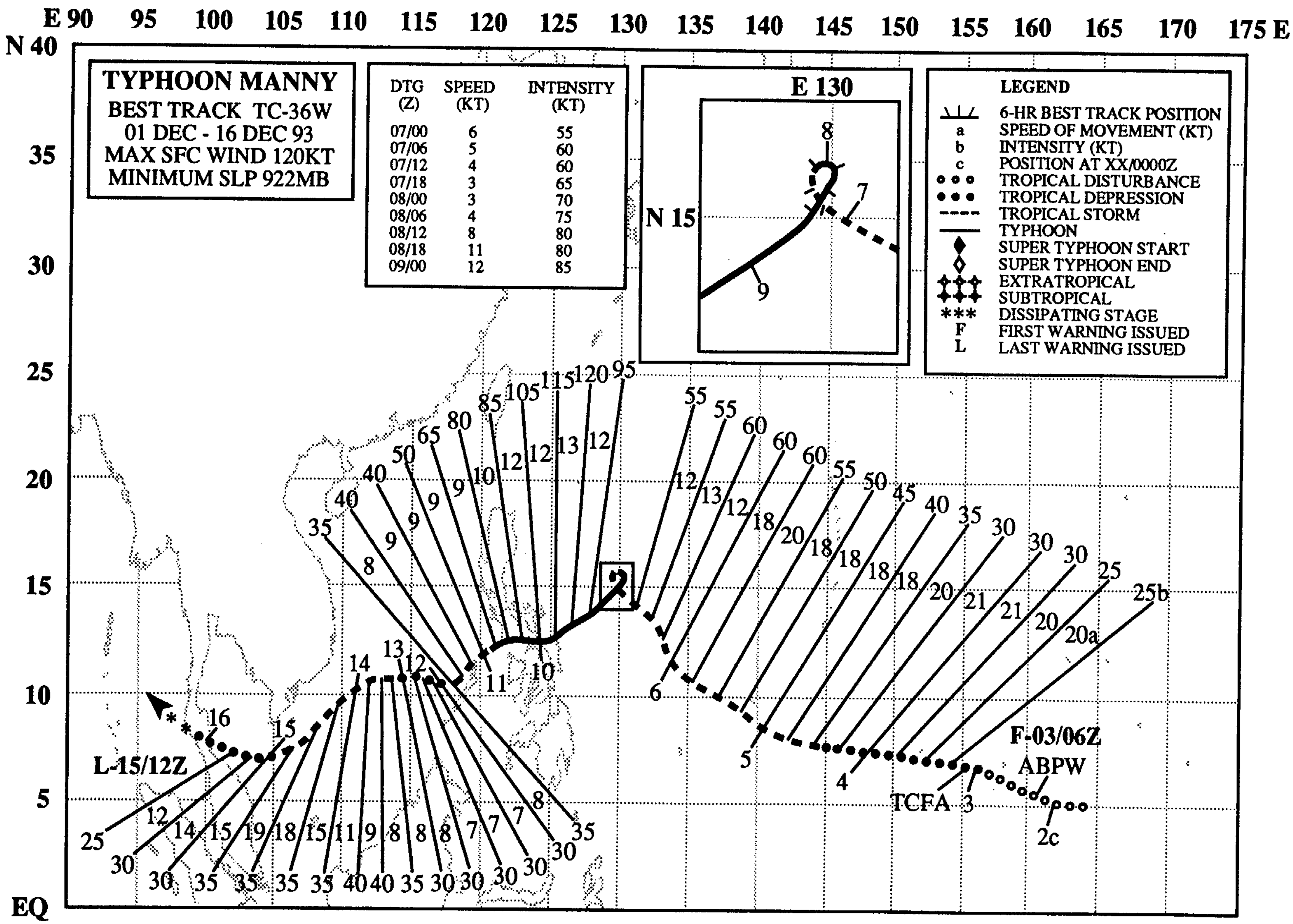
080000Z - After weakening over the Philippines and reintensifying in the South China Sea, Lola was upgraded to typhoon a second time based on a satellite intensity estimate of 65 kt (33 m/sec).

090600Z - The final warning for Lola was issued as it was rapidly dissipating over Vietnam.

III. IMPACT

In the Philippines, Lola killed over 230 people and forced more than 583,000 to flee their homes in the heavily populated Bicol region of southern Luzon near the city of Legazpi.

In southern Vietnam, the death toll was 78 with another 78 people reported missing. The region also suffered heavy agricultural losses with at least 40,000 acres of corn and 27,000 acres of rice destroyed.



DTG (Z)	SPEED (KT)	INTENSITY (KT)
07/00	6	55
07/06	5	60
07/12	4	60
07/18	3	65
08/00	3	70
08/06	4	75
08/12	8	80
08/18	11	80
09/00	12	85

TYPHOON MANNY (36W)

I. HIGHLIGHTS

The second of three typhoons to form in a very active near equatorial trough in December, Manny developed in the eastern Caroline Islands. After moving rapidly westward into the Philippine Sea, the tropical cyclone slowed and executed a cyclonic loop before tracking southwestward towards the Philippine Islands. Rapid intensification occurred as Manny approached the Philippine Islands. Once in the South China Sea, Manny, influenced by shear from the Asian northeast monsoon, weakened and meandered west-southwestward until it dissipated over the Malay Peninsula. Typhoon Manny was the 19th significant tropical cyclone of 1993 to directly affect the Philippines, and followed a track almost identical to that of Typhoon Pamela in 1982.

II. CHRONOLOGY OF EVENTS

December

020600Z - Typhoon Manny was first mentioned in the Significant Tropical Weather Advisory as an area of persistent convection within the near equatorial trough east of Pohnpei in the Caroline Islands.

030300Z - Increased convective organization and regional 24-hour pressure falls of 2 to 2.5 mb led to the issuance of a Tropical Cyclone Formation Alert.

030600Z - The first warning on Manny resulted from the combination of improved convective curvature, a satellite intensity estimate of 25 kt (13 m/sec), and surface synoptic data from the Caroline Islands which indicated that a closed low-level circulation was present.

041800Z - Manny was upgraded to tropical storm intensity based on a satellite intensity estimate of 45 kt (23 m/sec). Post analysis indicates that Manny most likely attained tropical storm intensity almost six hours earlier.

080000Z - The appearance of an eye and a satellite intensity estimate of 65 kt (33 m/sec) to an upgrade to typhoon intensity.

151200Z - Final warning was issued on Manny as it was dissipating over the Malay Peninsula.

III. IMPACT

On Yap (WMO 91413), Manny produced sustained winds of 38 kt (20 m/sec) with gusts to 47 kt (24 m/sec), resulting in some minor damage to banana trees, but not to structures. The tropical storm dropped 6.45 inches (165 mm) of rain on the Island. During the early morning hours of 10 December in the Philippine Islands, the typhoon swept across Samar killing at least eight people. This was only 75 nm (139 km) south of where Typhoon Lola (35W) had passed a week earlier, killing at least 230 people and forcing 583,000 to flee their homes.

IV. DISCUSSION

There are two interesting aspects of Manny: its track in the Philippine Sea was virtually identical to that of another typhoon, Pamela (December 1982); and, its rapid intensification while on a southwesterly track.

a. Clockwise loop in the Philippine Sea — On 7 December, Manny (Figure 3-36-1) entered a clockwise loop that took two days to complete. While Manny's motion was unusual, it was not unprecedented, and, in fact, has a near-perfect analog. Figure 3-36-2 compares the track of Manny with that of Typhoon Pamela (1982). Both typhoons performed a clockwise loop approximately 100 nm (185 km)

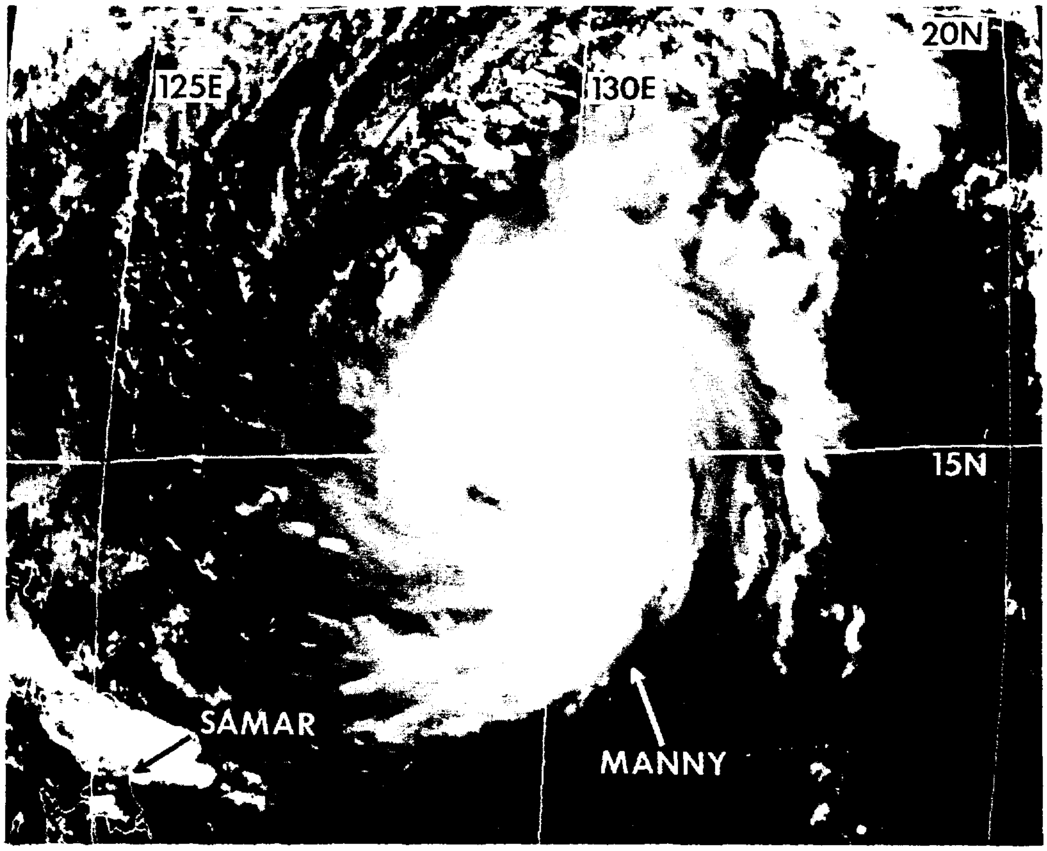


Figure 3-36-1 Approaching typhoon intensity, Manny begins to execute a clockwise loop in the Philippine Sea (070530Z December visual GMS imagery).

in diameter, tracked to the southwest and intensified.

b. Southwestward Track and Intensification — In tropical latitudes, tropical cyclones normally move in a direction north of west. Southwestward, tracks while not common, do occur with regularity. There are at least six distinct synoptic patterns that can cause a tropical cyclone to take a prolonged (24 hours or more) southwestward track. Four of these basic synoptic patterns are illustrated in Figure 3-36-3. The first synoptic pattern is the monsoon gyre (Figure 3-36-3a) described by Lander (1994). The second pattern, a surge in the northeast monsoon (Fig. 3-36-3b), occurs in the extreme western North Pacific and South China Sea from October through March. In this case, intensification is either short-lived or does not occur. The third pattern, induced ridging in low latitudes (Fig. 3-36-3c), may be associated with the reverse-oriented monsoon trough. The fourth pattern, dynamic ridging (Fig. 3-36-3d), is characterized by the subtropical ridge expanding. This expansion forces a tropical cylone to the southwest if the expansion is toward the southeast. Prior to the expansion a storm may respond to synoptic patterns that cause "stepping" and "looping" as identified by Sandgathe (1987). Although similar to the northeast monsoon pattern, tropical cyclones in the dynamic ridge pattern are less likely to weaken, and may even intensify significantly. The fifth and sixth synoptic patterns (not illustrated) are: southwestward motion associated with binary interaction, and tropical cyclones (usually TUTT-induced) that develop in the trade winds between the axes of the monsoon trough and the subtropical ridge. Of the six synoptic patterns, the dynamic ridge pattern (Figure 3-36-3d) applies to the movement of Manny while it was in the Philippine Sea.

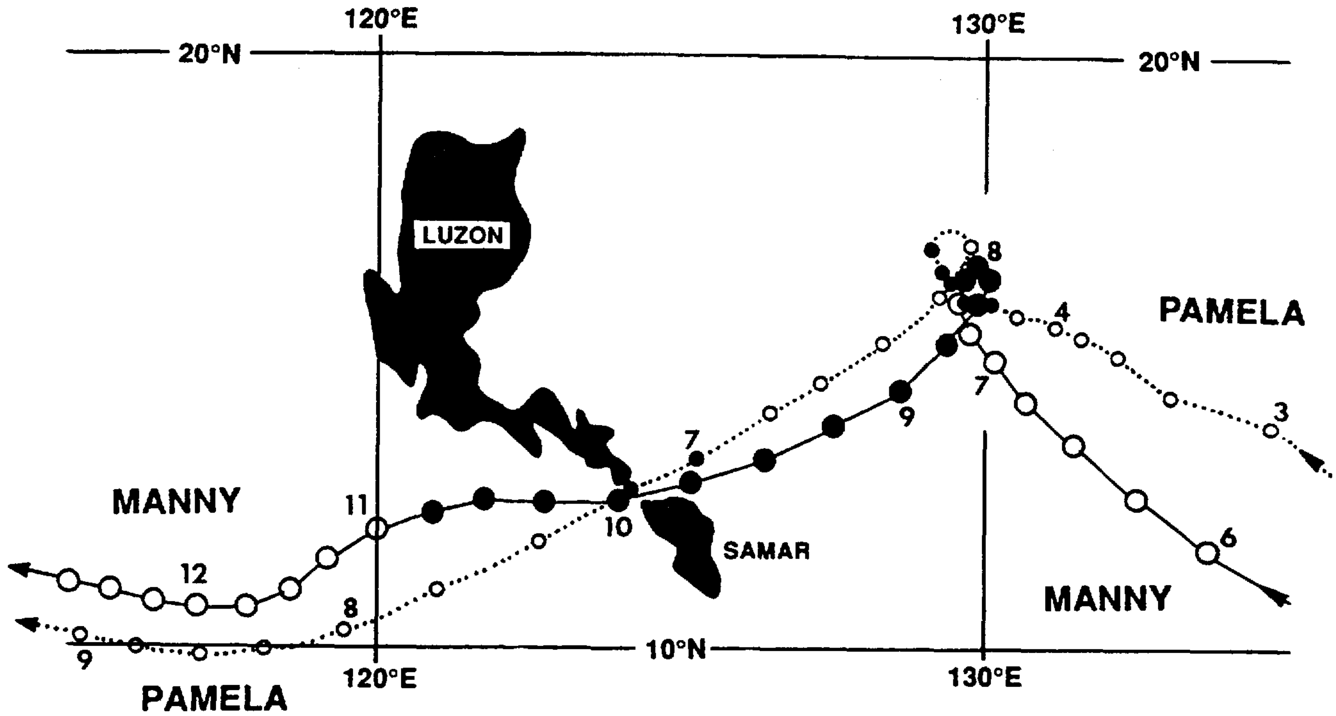


Figure 3-36-2 A comparison of the December tracks of Typhoons Manny (1993) and Pamela (1982). Both typhoons executed a clockwise loop in virtually the same location, and both intensified on their subsequent southwestward tracks. Manny's track is depicted by large circles connected by solid lines and Pamela's track is depicted by small circles connected with dotted lines. Tropical storm intensities are designated with open circles and typhoon intensities with filled circles. Dates at 0000Z are indicated by small numbers.

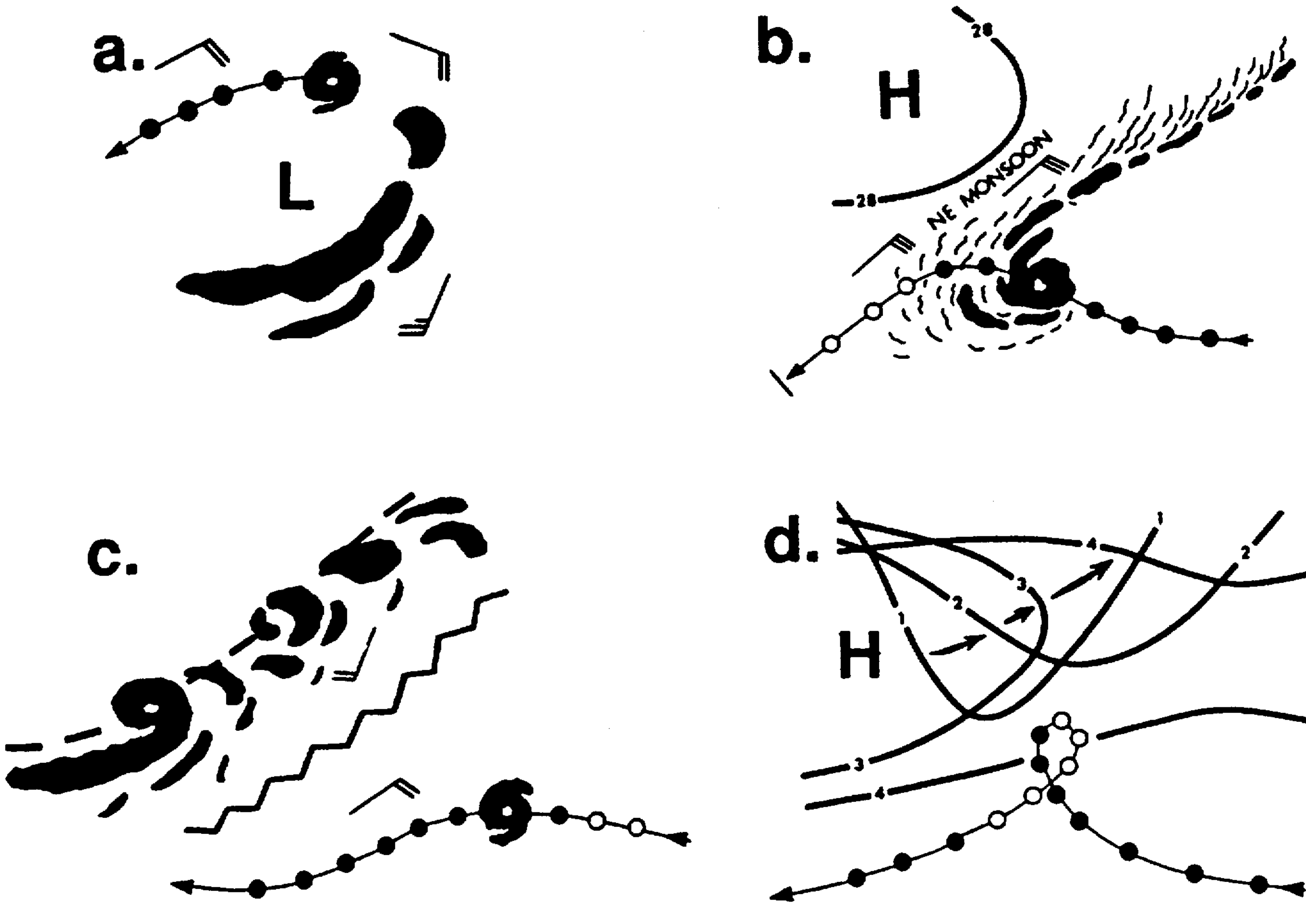
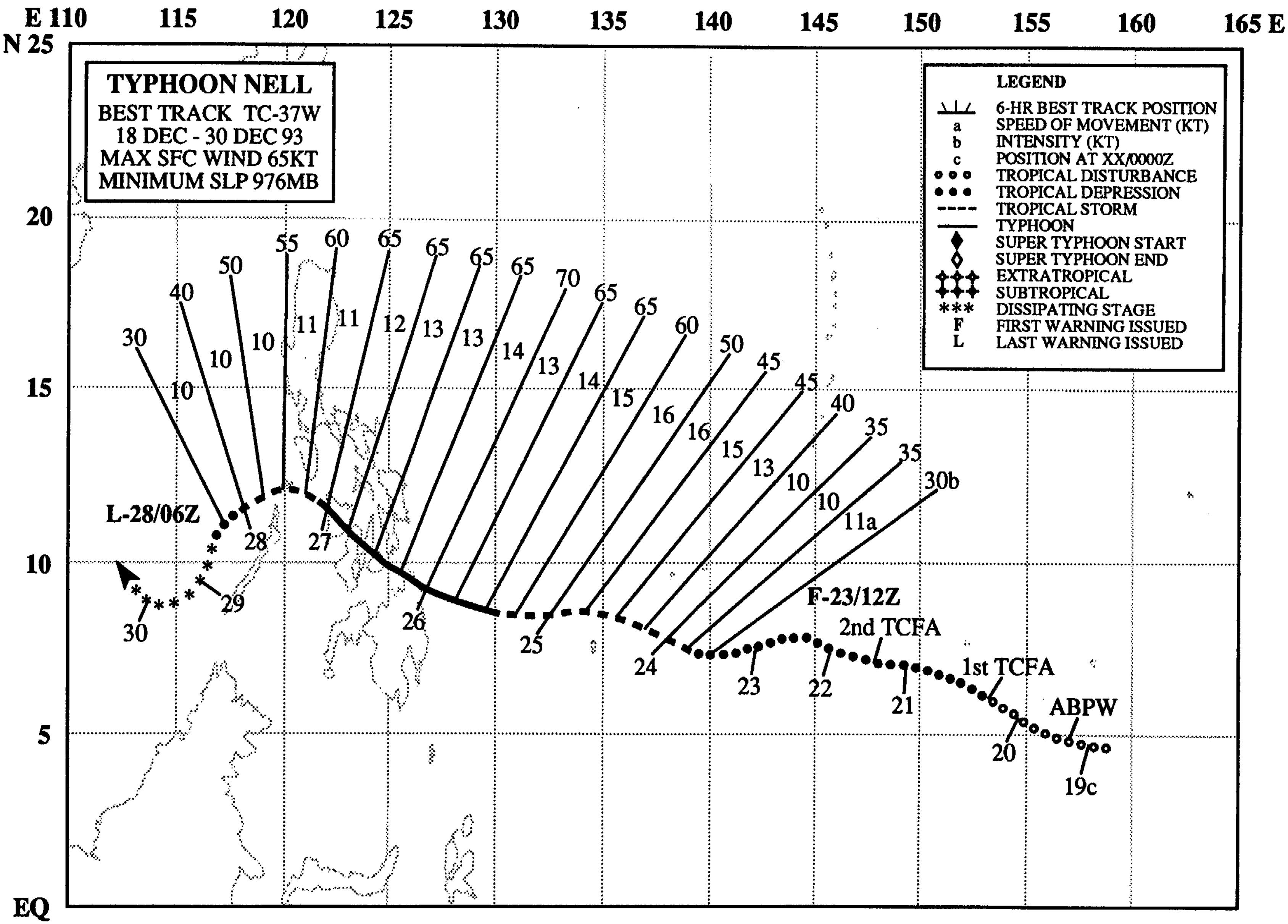


Figure 3-36-3 Primary synoptic patterns that cause tropical cyclones to move on a prolonged southwestward track: (a) Monsoon gyre, (b) northeast monsoon surge, (c) Induced ridging in low latitudes, and (d) dynamic ridging. Tropical cyclone track is depicted by circles connected by solid lines. Tropical storm intensities are designated by an open circle, typhoon intensities by filled circle. The 28 Isopleths in panel b means 1028 mb and numbers in panel d (1,2,3 and 4) indicate sequential daily movement.


TYPHOON NELL
BEST TRACK TC-37W
18 DEC - 30 DEC 93
MAX SFC WIND 65KT
MINIMUM SLP 976MB
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 110
115
120
125
130
135
140
145
150
155
160
165 E
N 25
20
15
10
5
EQ
L-28/06Z
F-23/12Z
2nd TCFA
1st TCFA
ABPW
30b
11a
19c
20
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22
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30

TYPHOON NELL (37W)

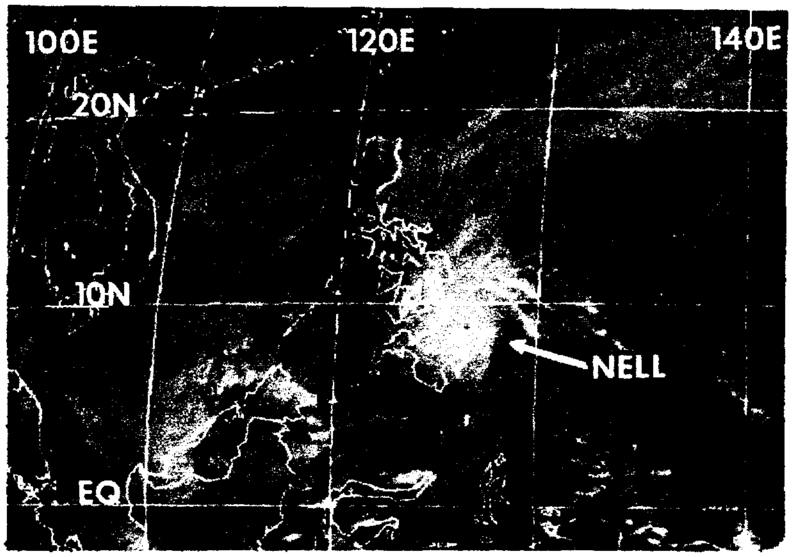


Figure 3-37-1 Typhoon Nell at peak intensity near Mindanao close to the time of landfall (260132Z December visual GMS imagery).

I. HIGHLIGHTS

The final tropical cyclone of the 1993 season, Typhoon Nell, developed south of Pohnpei in an active near equatorial trough. Embedded in a high vertical shear environment, Nell developed slowly while tracking westward through the Caroline Islands. Intensifying to typhoon strength before crossing the Philippines (Figure 3-37-1), Nell maintained typhoon intensity while crossing the islands. Once in the South China Sea, Nell entered a high vertical shear environment and quickly dissipated.

II. CHRONOLOGY OF EVENTS

December

190600Z - An area of persistent convection within the monsoon trough resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

201300Z - A Tropical Cyclone Formation Alert (TCFA) was issued based on the development of deep convection near the circulation center and an overall improvement in organization.

211300Z - Although the disturbance did not intensify during the first TCFA, conditions remained favorable for development and a second TCFA was issued.

221300Z - The TCFA was canceled as the convection decreased steadily.

231200Z - The first warning was issued without a TCFA in effect, based on improved convective organization and a satellite intensity estimate of 25 kt (13 m/sec).

250000Z - A satellite intensity estimate of 35 kt (18 m/sec), led to the upgrade of Nell to a tropical storm. Post analysis indicates that Nell likely became a tropical storm over a day earlier, at 231800Z.

260000Z - Based on the first daylight satellite intensity estimate of 65 kt (33 m/sec), Nell was upgraded to a typhoon. Post analysis indicates that Nell actually achieved typhoon intensity about 12 hours earlier.

280600Z - The final warning was issued on Nell as it dissipated in the South China Sea in a high shear environment.

III. IMPACT

News agencies attributed seven deaths to Nell, six at Surigao City, Mindanao, near the area of landfall. Additionally, thousands of residents in low-lying river valleys in northern Mindanao were forced to evacuate to higher ground.

3.2 NORTH INDIAN OCEAN TROPICAL CYCLONES

Spring and fall in the North Indian Ocean are periods of transition between major climatic controls, and are the most favorable seasons for tropical cyclone activity. This year, only two significant tropical cyclones occurred, both in the fall transition month of November (Table 3-5). This amount of activity was unusually low for an ocean basin which typically experiences an average of five, and in sharp contrast to the previous year, 1992, which set a 18-year record high of 13 (Table 3-6). The last time only two tropical cyclones were recorded was 13 years earlier in 1980.

The best track composites for TC01A and TC02B are shown in Figure 3-14. Tropical Cyclone 01A formed in mid-November in conjunction with a twin, TC01S (Alexina), in the Southern Hemisphere. Later, at the end of the month, when the monsoon trough became active across the western North Pacific and Bay of Bengal, TC02B formed. During the first week of December, TC02B became part of a multiple storm outbreak along with Lola (35W) and Manny (36W).

Table 3-5 NORTH INDIAN OCEAN SIGNIFICANT TROPICAL CYCLONES FOR 1993

TROPICAL CYCLONE	PERIOD OF WARNING	NUMBER OF WARNINGS ISSUED	MAXIMUM SURFACE WINDS-KT (M/SEC)	ESTIMATED MSLP (MB)
TC 01A	12 NOV - 16 NOV	5	80 (41)	963
TC 02B	30 NOV - 05 DEC	6	75 (39)	967
	TOTAL	11		

The criteria used in Table 3-6 are as follows:

1. If a tropical cyclone was first warned on during the last two days of a particular month and continued into the next month for longer than two days, then that system was attributed to the second month.
2. If a tropical cyclone was warned on prior to the last two days of a month, it was attributed to the first month, regardless of how long the system lasted.
3. If a tropical cyclone began on the last day of the month and ended on the first day of the next month, that system was attributed to the first month. However, if a tropical cyclone began on the last day of the month and continued into the next month for only two days, then it was attributed to the second month.

TABLE 3-6 LEGEND

	2		
Total for the month/year →		2	
Typhoons →	2	0	0
Tropical Storms ↗			
Tropical Depressions ↗			

Table 3-6 DISTRIBUTION OF NORTH INDIAN OCEAN TROPICAL CYCLONES FOR 1975-1993

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTALS
1975	1	0	0	0	2	0	0	0	0	1	2	0	6
	010	000	000	000	200	000	000	000	000	100	020	000	3 3 0
1976	0	0	0	1	0	1	0	0	1	1	0	1	5
	000	000	000	010	000	010	000	000	010	010	000	010	0 5 0
1977	0	0	0	0	1	1	0	0	0	1	0	2	5
	000	000	000	000	010	010	000	000	000	010	000	110	1 4 0
1978	0	0	0	0	1	0	0	0	0	1	2	0	4
	000	000	000	000	000	000	000	000	000	010	200	000	2 2 0
1979	0	0	0	0	1	1	0	0	2	1	2	0	7
	000	000	000	000	100	010	000	000	011	010	011	000	1 4 2
1980	0	0	0	0	0	0	0	0	0	0	1	1	2
	000	000	000	000	000	000	000	000	000	000	010	010	0 2 0
1981	0	0	0	0	0	0	0	0	1	0	1	1	3
	000	000	000	000	000	000	000	000	010	000	100	100	2 1 0
1982	0	0	0	0	1	1	0	0	0	2	1	0	5
	000	000	000	000	100	010	000	000	000	020	100	000	2 3 0
1983	0	0	0	0	0	0	0	1	0	1	1	0	3
	000	000	000	000	000	000	000	010	000	010	010	000	0 3 0
1984	0	0	0	0	1	0	0	0	0	1	2	0	4
	000	000	000	000	010	000	000	000	000	010	200	000	2 2 0
1985	0	0	0	0	2	0	0	0	0	2	1	1	6
	000	000	000	000	020	000	000	000	000	020	010	010	0 6 0
1986	1	0	0	0	0	0	0	0	0	0	2	0	3
	010	000	000	000	000	000	000	000	000	000	020	000	0 3 0
1987	0	1	0	0	0	2	0	0	0	2	1	2	8
	000	010	000	000	000	020	000	000	000	020	010	020	0 8 0
1988	0	0	0	0	0	1	0	0	0	1	2	1	5
	000	000	000	000	000	010	000	000	000	010	110	010	1 4 0
1989	0	0	0	0	1	1	0	0	0	0	1	0	3
	000	000	000	000	010	010	000	000	000	000	100	000	1 2 0
1990	0	0	0	1	1	0	0	0	0	0	1	1	4
	000	000	000	001	100	000	000	000	000	000	001	010	1 1 2
1991	1	0	0	1	0	1	0	0	0	0	1	0	4
	010	000	000	100	000	010	000	000	000	000	010	000	1 3 0
1992	0	0	0	0	1	2	1	0	1	3	3	2	13
	000	000	000	000	100	020	010	000	001	021	210	020	3 8 2
1993	0	0	0	0	0	0	0	0	0	0	2	0	2
	000	000	000	000	000	000	000	000	000	000	200	000	2 0 0
(1975-1993)													
AVERAGE	0.2	0.1	0.0	0.2	0.6	0.6	0.1	0.1	0.3	0.9	1.5	0.5	4.8
CASES	3	1	0	3	12	11	1	1	5	17	28	10	92

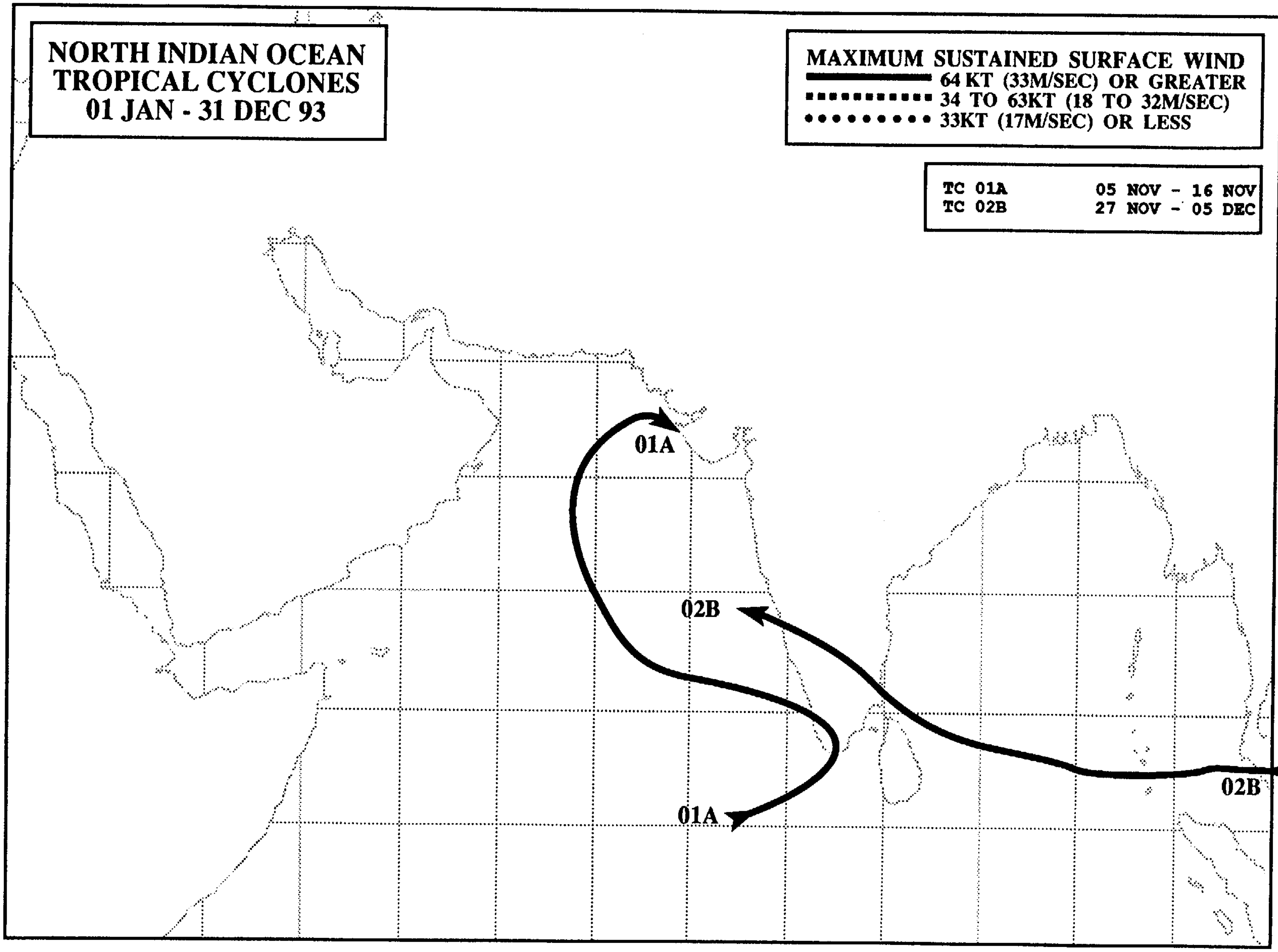
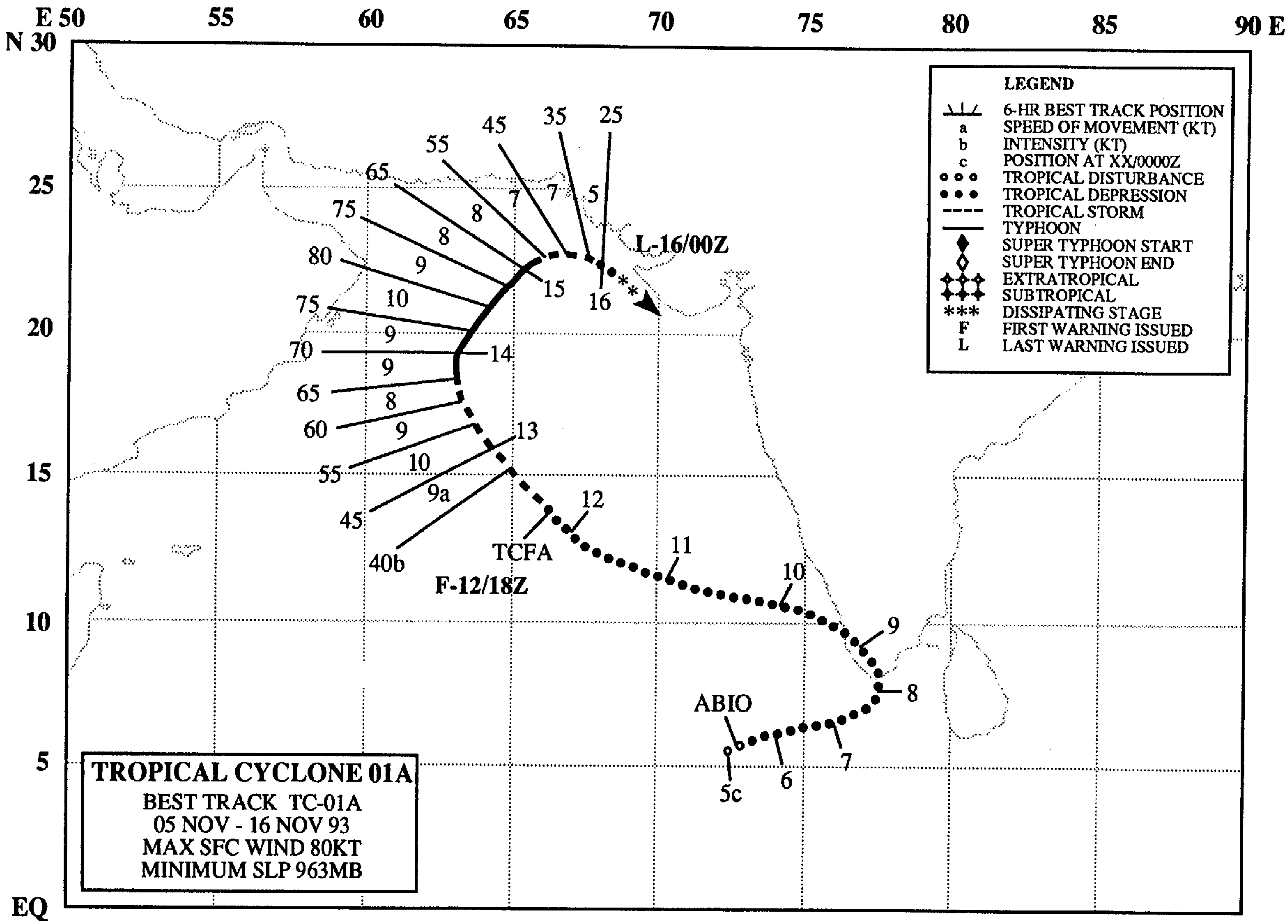


Figure 3-14 Composite best track for the North Indian Ocean tropical cyclones for 1993.


E 50
55
60
65
70
75
80
85
90 E
N 30
25
20
15
10
5
EQ
LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
L-16/00Z
F-12/18Z
TCFA
ABIO
TROPICAL CYCLONE 01A
BEST TRACK TC-01A
05 NOV - 16 NOV 93
MAX SFC WIND 80KT
MINIMUM SLP 963MB

TROPICAL CYCLONE 01A

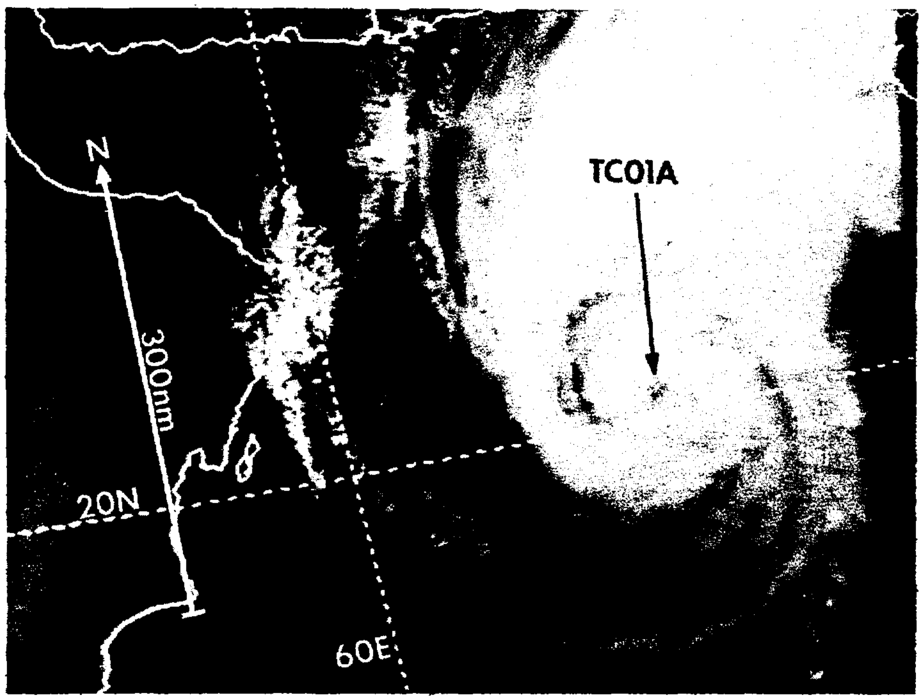


Figure 3-01A-1 TC 01A in the central Arabian Sea is within 12 hours of reaching its peak intensity of 80 kt (41 m/sec) (140059Z November visible DMSP image).

I. HIGHLIGHTS

The only significant tropical cyclone to occur in the Arabian Sea during 1993, Tropical Cyclone 01A (TC 01A), originated southwest of India. After persisting for a week, TC 01A entered a low shear environment and steadily intensified to 80 kt (41 m/sec) (Figure 3-01A-1). Following recurvature to the northeast and attainment of peak intensity on 14 November, the tropical cyclone entered a region of high vertical shear near the Pakistan-India border and dissipated over water.

II. CHRONOLOGY OF EVENTS

November

050600Z - An area of persistent convection caused JTWC to mention the disturbance in the Significant Tropical Weather Advisory.

120600Z - A TCFA was issued on the developing disturbance based on an increase in convection near the low-level circulation center.

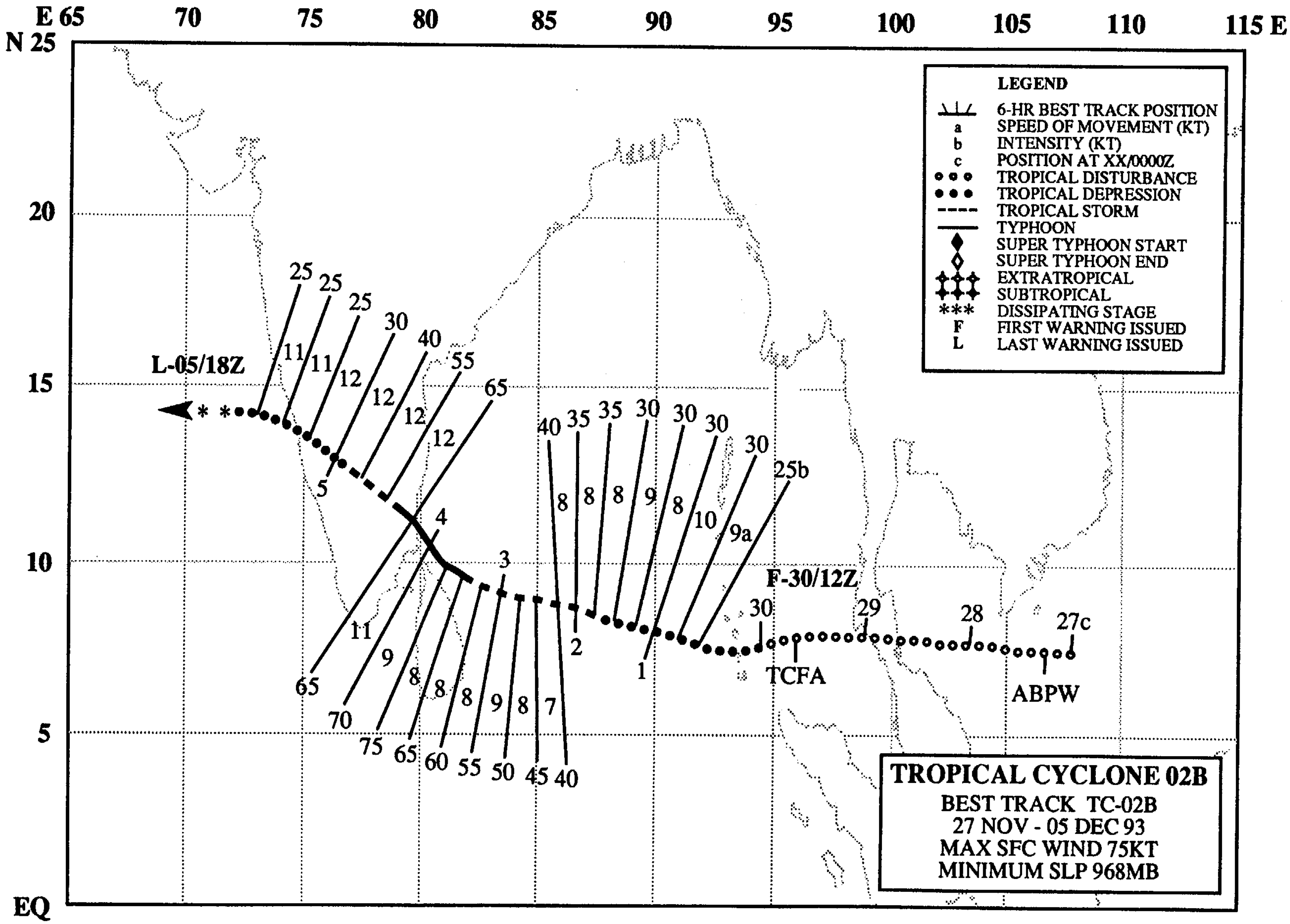
121800Z - The first warning was issued on TC 01A based on a satellite intensity estimate of 35 kt (18 m/sec).

131800Z - Based upon a satellite intensity estimate of 65 kt (33 m/sec) led forecasters to upgrade TC 01A to typhoon intensity.

160000Z - The final warning was issued on TC 01A as the system dissipated over water.

III. IMPACT

No reports received.


LEGEND
6-HR BEST TRACK POSITION
a SPEED OF MOVEMENT (KT)
b INTENSITY (KT)
c POSITION AT XX/0000Z
TROPICAL DISTURBANCE
TROPICAL DEPRESSION
TROPICAL STORM
TYPHOON
SUPER TYPHOON START
SUPER TYPHOON END
EXTRATROPICAL
SUBTROPICAL
*** DISSIPATING STAGE
F FIRST WARNING ISSUED
L LAST WARNING ISSUED
E 65
70
75
80
85
90
95
100
105
110
115 E
N 25
20
15
10
5
EQ
L-05/18Z
F-30/12Z
TCFA
ABPW
25b
27c
9a
TROPICAL CYCLONE 02B
BEST TRACK TC-02B
27 NOV - 05 DEC 93
MAX SFC WIND 75KT
MINIMUM SLP 968MB

TROPICAL CYCLONE 02B

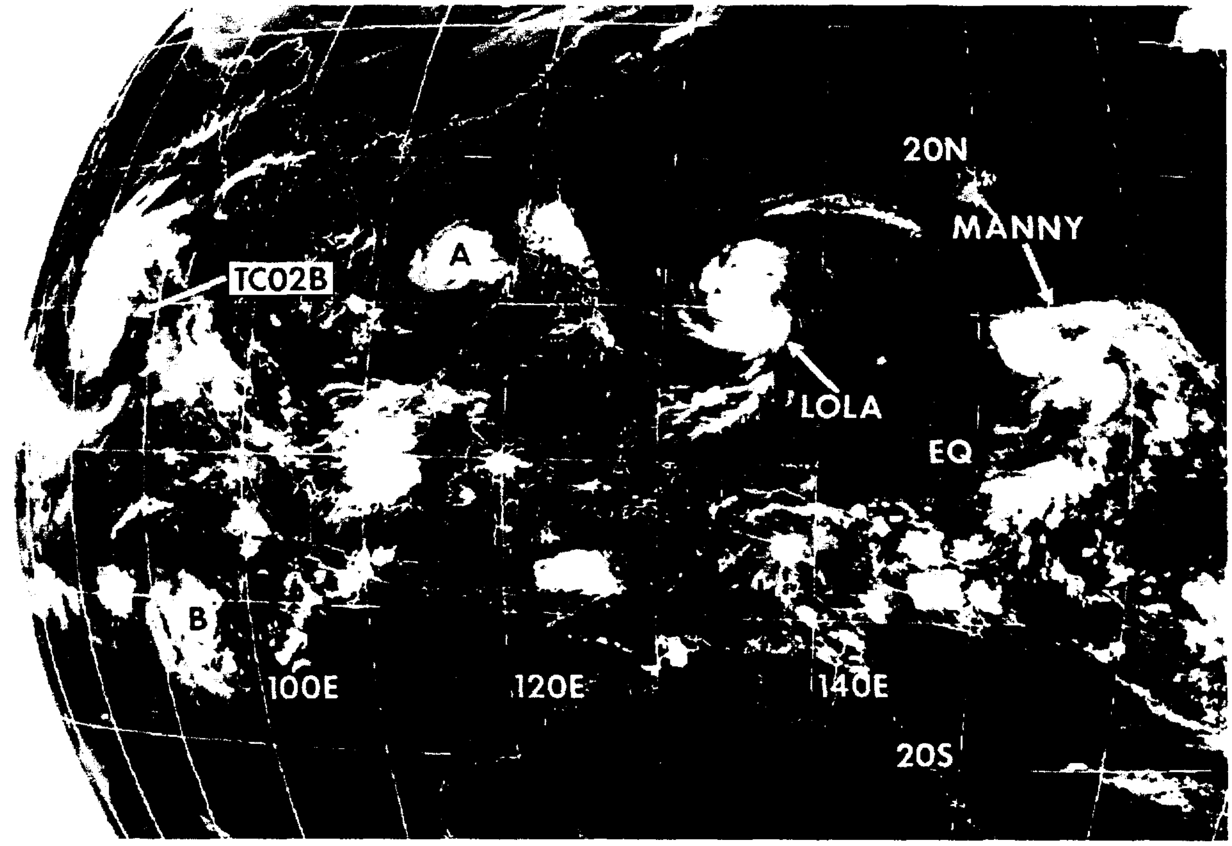


Figure 3-02B-1 TC 02B is part of a multiple storm outbreak that includes: Lola (35W) and Manny (36W) in the western North Pacific, and two tropical disturbances, (A) and (B), in the South China Sea and South Indian Ocean, respectively.

I. HIGHLIGHTS

The only significant tropical cyclone to affect the Bay of Bengal during 1993, Tropical Cyclone 02B (TC 02B), originated in the South China Sea. After passing over the Malay Peninsula, TC 02B tracked westward towards Sri Lanka and southern India while steadily intensifying. Before TC 02B passed over southern India and dissipated just off shore in the Arabian Sea, it became part of a multiple storm outbreak (Figure 3-02B-1).

II. CHRONOLOGY OF EVENTS

November

270600Z - An area of persistent convection, south of Vietnam, resulted in the first mention of the disturbance in the Significant Tropical Weather Advisory.

291630Z - A Tropical Cyclone Formation Alert was issued based on an increase in convection and synoptic data which indicated a weak surface cyclonic circulation.

301200Z - The first warning was issued based on a satellite intensity estimate of 25 kt (13 m/sec).

December

031200Z - Based on a satellite intensity estimate of 65 kt (33 m/sec), TC 02B was upgraded to typhoon intensity.

051800Z - The final warning was issued after TC 02B traversed southern India, entered the Arabian Sea, and dissipated.

III. IMPACT

None.

Captions:

Figure 3-01A-1 TC 01A in the central Arabian Sea is within 12 hours of reaching its peak intensity of 80 kt (41 m/sec) (140059Z November visible DMSP image).

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